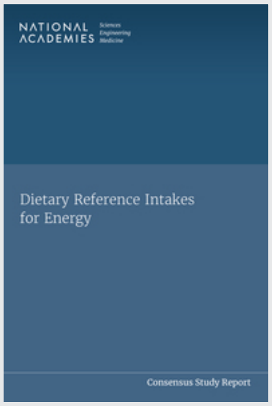

Dietary Reference Intakes for Energy (2023)

DETAILS

542 pages | 6 x 9 | PAPERBACK
ISBN 978-0-309-69723-1 | DOI 10.17226/26818

CONTRIBUTORS

Committee on the Dietary Reference Intakes for Energy; Food and Nutrition Board; Health and Medicine Division; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2023. *Dietary Reference Intakes for Energy*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26818.

NATIONAL ACADEMIES Sciences Engineering Medicine

NATIONAL ACADEMIES PRESS
Washington, DC

Dietary Reference Intakes for Energy

Committee on Dietary Reference Intakes for Energy

Food and Nutrition Board

Health and Medicine Division

Consensus Study Report

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, NW Washington, DC 20001

This activity was supported by contracts between the National Academy of Sciences and Health Canada (Contract #4500431935), the National Institutes of Health (Contract #HHSN263201800029I/75N98021F00007), the U.S. Department of Agriculture (Contract #59-0204-1-005), and the U.S. Food and Drug Administration (Contract #75F40121C00075). Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

International Standard Book Number-13: 978-0-309-69723-1
International Standard Book Number-10: 0-309-69723-9
Digital Object Identifier: https://doi.org/10.17226/26818

This publication is available from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu.

Printed in the United States of America.

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2023. *Dietary Reference Intakes for energy*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26818.

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, nongovernmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. John L. Anderson is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.nationalacademies.org**.

Consensus Study Reports published by the National Academies of Sciences, Engineering, and Medicine document the evidence-based consensus on the study's statement of task by an authoring committee of experts. Reports typically include findings, conclusions, and recommendations based on information gathered by the committee and the committee's deliberations. Each report has been subjected to a rigorous and independent peer-review process, and it represents the position of the National Academies on the statement of task.

Proceedings published by the National Academies of Sciences, Engineering, and Medicine chronicle the presentations and discussions at a workshop, symposium, or other event convened by the National Academies. The statements and opinions contained in proceedings are those of the participants and are not endorsed by other participants, the planning committee, or the National Academies.

Rapid Expert Consultations published by the National Academies of Sciences, Engineering, and Medicine are authored by subject-matter experts on narrowly focused topics that can be supported by a body of evidence. The discussions contained in rapid expert consultations are considered those of the authors and do not contain policy recommendations. Rapid expert consultations are reviewed by the institution before release.

For information about other products and activities of the National Academies, please visit www.nationalacademies.org/about/whatwedo.

COMMITTEE ON DIETARY REFERENCE INTAKES FOR ENERGY

ANNA MARIA SIEGA-RIZ (*Chair*), University of Massachusetts Amherst
REGAN L. BAILEY, Texas A&M University, College Station
ETHAN M. BALK, Brown University School of Public Health, Providence, Rhode Island
SUSAN I. BARR, University of British Columbia, Vancouver, Canada
LONEKE T. BLACKMAN CARR, University of Connecticut, Storrs (until May 9, 2022)
NANCY F. BUTTE, Baylor College of Medicine, Houston, Texas
SCOTT E. CROUTER, University of Tennessee, Knoxville
AMY H. LUKE, Loyola University Chicago, Maywood, Illinois
SUSAN B. ROBERTS, Tufts Medical School, Boston, Massachusetts (until June 16, 2022)
HEIDI J. SILVER, Vanderbilt University Medical Center, Nashville, Tennessee
JANET A. TOOZE, Wake Forest School of Medicine, Winston Salem, North Carolina
WILLIAM W. WONG, Baylor College of Medicine, Houston, Texas
ELIZABETH A. YETLEY (*Retired*), National Institutes of Health, Bethesda, Maryland

Consultants

RICHARD TROIANO (*Retired*), National Institutes of Health, Bethesda, Maryland
DAVID ALLISON, Indiana University School of Public Health-Bloomington
CARMEN TEKWE, Indiana University School of Public Health-Bloomington
ROGER ZOH, Indiana University School of Public Health-Bloomington
STEPHANIE DICKINSON, Indiana University School of Public Health-Bloomington
LILIAN GOLZARRI ARROYO, Indiana University School of Public Health-Bloomington
AARON COHEN, Indiana University School of Public Health-Bloomington
JOCELYN MINEO, Indiana University School of Public Health-Bloomington

Health and Medicine Division Staff

ANN L. YAKTINE, Study Director
ALICE VOROSMARTI, Associate Program Officer
MELANIE ARTHUR, Senior Program Assistant

Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

JAMY D. ARD, Wake Forest University School of Medicine
DEEPA HANDU, Academy of Nutrition and Dietetics
STEVEN B. HEYMSFIELD, Louisiana State University System
MARIAN L. NEUHOUSER, Fred Hutchinson Cancer Center
USHA RAMAKRISHNAN, Emory University
LEANNE REDMAN, Pennington Biomedical Research Center
CATHERINE ROSS, Pennsylvania State University
BARBARA SCHNEEMAN, University of California, Davis (Emerita)
DALE A. SCHOELLER, University of Wisconsin-Madison
ANNA THALACKER-MERCER, University of Alabama at Birmingham

STELLA LUCIA VOLPE, Virginia Polytechnic Institute and State University

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by **ENRIQUETA C. BOND,** Burroughs Wellcome Fund, and **CATHERINE E. WOTEKI,** Iowa State University. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

Preface

This committee focused on updating the Dietary Reference Intakes (DRI) for energy for the U.S. and Canadian populations. The previous update occurred in 2002–2005 within a report that included DRIs for energy and macronutrients. This committee's work is of critical importance given that the DRI for energy is widely used to provide guidance for maintaining energy balance in individuals of a defined age, sex, weight, height, and level of physical activity. For example, within health care settings, practitioners use these recommendations to counsel patients on how to attain or maintain an appropriate weight given certain health conditions. Health care practitioners also use the recommendations to advise pregnant women on dietary intake to support adequate weight gain during pregnancy and to advise lactating women on appropriate weight change in the postpartum period, topics that are also covered in registered dietitians' counseling of Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participants. As another example, the school breakfasts and lunches served each school day to millions of students across the United States and Canada are based on these energy requirements in an effort to keep children healthy, growing, and in optimal states for learning. Although these recommendations have a margin of error inherent in any equation-based DRI, they provide a solid baseline and allow individuals and planners to monitor energy balance to enhance the general health of individuals and of the populations.

In this revision of the DRI for energy, the committee's work included two major changes. One was a change in the referent population to which the DRI can be applied. In an effort to be more inclusive of all individuals living in the United States and Canada—where a greater proportion of the populations are living with a chronic disease—the referent population is now the general population instead of the healthy population. We thank the DRI Standing Committee for their consultation on this matter, which led to the committee's final decision to make this change. The second change was to build a more comprehensive doubly labeled water (DLW) database by using multiple sources, including the International Atomic Energy Agency (IAEA) and the Hispanic Community Health Study (SOLNAS). We thank Dr. John Speakman from IAEA and Dr. John Kunz from the National Heart, Lung, and Blood Institute for facilitating the committee's use of these data. Furthermore, we are especially appreciative of the work conducted by the team at Indiana University School of Public Health-Bloomington (Dean David Allison, Dr. Carmen Tekwe, Dr. Roger Zoh, Stephanie Dickinson, Lilian Golzarri Arroyo, Jocelyn Mineo, and Aaron Cohen) that performed the data management and statistical analyses to derive the equations for energy expenditure. The compilation of new DLW data combined with the data used in the Institute of Medicine's 2002/2005 report on DRIs for energy and macronutrients greatly enhanced our ability to develop more accurate prediction equations for estimating total energy expenditure.

We were fortunate to have the support of Cynthia Ogden at the Centers for Disease Control and Prevention and The Minh Luong and Dominque Ibañez at Statistics Canada in providing us with current data from national nutrition monitoring surveys for inclusion in the report. These data allowed the committee to assess current intakes and energy status among U.S. and Canadian life-stage groups and provided background information for evaluating the public health implications associated with deviations from the proposed Estimated Energy Requirement (EER).

Several presenters provided the committee with cutting-edge, state-of-the-art information for it to consider as it conducted its work. The committee thanks John Jakicic, John Speakman, Kevin Hall, Rick Troiano, Leanne Redman, Kellie Casavale, and Kathryn Hopperton for taking the time to present their important work.

As committee chair, I greatly appreciate the National Academies staff—Ann Yaktine, Alice Vorosmarti, Melanie Arthur, Katie Delaney, Hoda Soltani, and Rebecca Morgan—for the tremendous amount of professionalism and support provided to the committee in conducting its work. I am impressed by their dedication and high standards for using best practices to develop consensus reports containing policy recommendations. Lastly, I applaud the work of the committee members and our physical activity consultant, Dr. Rick Troiano, in coming together, volunteering their time, effort, expertise, and patience in taking on this important task and doing so in such a rigorous, respectful manner.

Anna Maria Siega-Riz, Chair
Committee on Dietary Reference
Intakes for Energy

Contents

Summary

Energy is required to sustain the body's various functions, including respiration, circulation, physical work, and protein synthesis. This energy is derived from dietary carbohydrates, proteins, fats, and to a lesser extent, alcohol. Energy balance depends on an individual's dietary energy intake and energy expenditure. The Dietary Reference Intake (DRI) value for energy is the Estimated Energy Requirement (EER), which is defined as the average dietary energy intake that is predicted to maintain energy balance in an adult of a defined age, sex, weight, height, level of physical activity, and life stage, consistent with maintaining health.

The DRIs for energy are used widely to provide guidance for maintaining energy balance on both an individual and group level. Applications include health care settings, support for federal nutrition policies such as the U.S. *Dietary Guidelines for Americans* and the Canadian *Dietary Guidelines*, and public feeding programs such as school meals. The DRIs for energy also serve as a critical data resource to support military nutrition standards and nutrition counseling and education programs.

The need to reexamine the DRIs for energy, last updated in 2005, stemmed from two key factors. First, both the U.S. and Canadian populations have experienced an imbalance in their energy intake and expenditure during the past several decades, such that weight status has trended toward overweight and obesity across demographic groups. Second, new scientific evidence has advanced knowledge about the energy intake and expenditure through the use of doubly labeled water (DLW) analysis.

This update of the DRIs for energy includes two major changes. First, the DRI population was considered relative to the health status of the U.S. and Canadian populations. To be more inclusive of those in the population who have or are at risk for chronic disease, the DRI population is now defined as the general population, including those with overweight, obesity, and chronic diseases, rather than the previous "generally healthy" population. Second, the data source for DLW was expanded to include databases that represent more diverse population groups.

STUDY TASK

The U.S. and Canadian governments asked the National Academies to convene an expert committee to examine the evidence and recommend updated EERs for their populations. Specifically, the committee was asked to assess the human requirements for energy intake and expenditure, and to consider age, sex, body size, body composition, level of physical activity, race/ethnicity, and other factors that may be warranted, based on the available data. Other significant variables for consideration included energy for growth and maturation for children, energy needs to support pregnancy, energy costs of milk production for lactating women, energy intake to achieve and maintain weight loss or weight gain, energy requirements to support recovery from disease and treatments or interventions such as surgery, and the health consequences of chronic overnutrition or undernutrition across the life span. The committee was asked to use data from studies that have incorporated DLW data, which are considered the benchmark standard to assess energy expenditure, to update the EER equations.

APPROACH TO THE TASK

The committee's approach to gathering evidence published since the original DRIs for energy was to first conduct an umbrella review—a review of existing systematic reviews relevant to the questions in the statement of task. If no existing systematic reviews were found for topics that the committee considered to be of highest priority, the umbrella review was supplemented with relevant studies from the peer-reviewed published literature. This evidence-gathering approach differs from the two previous DRI updates, which included conducting new or updating existing systematic reviews prior to committee deliberations as the primary evidence base to support key committee deliberations, and from the narrative review approach used in the original DRIs, which would not support the range or the quality of evidence the committee needed to carry out its task.

For its DLW data, the committee assembled a database comprising data obtained from the International Atomic Energy Agency (IAEA), the Institute of Medicine (IOM), the Hispanic Community Health Study of Latinos: Nutrition & Physical Activity Assessment Study (SOLNAS), and the Children's Nutrition Research Center at the Baylor College of Medicine (CNRC). The committee's database provided the following variables: total energy expenditure (TEE), age category, age, life stage, ethnicity, sex, body mass index (BMI), height, weight, basal metabolic rate (BMR) observed, BMR predicted, lactating, pregnant, gestational weeks, physical activity level (PAL) observed, PAL category observed, PAL predicted, PAL category predicted, fat-free mass (FFM), fat mass (FM), and FM percent.

EQUATIONS TO ESTIMATE TOTAL ENERGY EXPENDITURE

The committee engaged a consultant group to analyze the DLW data and generate prediction equations for TEE by age/sex and life-stage groups. In a weight-stable person, TEE is the most accurate measure of a person's EER. The original EERs accounted for variability in physical activity by incorporating PAL, representing four categories as *sedentary*, *low active*, *active*, and *very active* as a variable (IOM, 2002/2005). The same PAL thresholds were used to define the categories across all life stages except infancy. However, recent evidence indicates that the physical activity level coefficient is not constant but varies significantly across age groups, particularly during the first 20 years of life, thus the previous PAL coefficients could not be used for all life stages. Therefore, an approach was developed to incorporate the age dependency into PAL categories for the development of the TEE prediction equations.

The committee used multiple methods to determine a PAL category (PALCAT). These methods by themselves could misclassify an individual, but taken together they provide a more thorough approach to capture the correct category. The PAL categories are *inactive*, *low active*, *active*, and *very active*. In the cases of pregnancy, lactation, and childhood (birth to 18 years of age), the committee also incorporated into the equations an allowance for growth, tissue accretion, and milk production in addition to TEE. The final TEE prediction equations used to derive the EERs are shown in Table S-1.

TABLE S-1 TEE Prediction Equations by Age/Sex and Life-Stage Group

Men, 19 years and above	
Inactive	TEE = 753.07 – (10.83 × age) + (6.50 × height) + (14.10 × weight)
Low active	TEE = 581.47 – (10.83 × age) + (8.30 × height) + (14.94 × weight)
Active	TEE = 1,004.82 – (10.83 × age) + (6.52 × height) + (15.91 × weight)
Very active	TEE = – 517.88 – (10.83 × age) + (15.61 × height) + (19.11 × weight)
NOTE: R^2 = 0.73; R^2 adj = 0.73; R^2 shr = 0.73; RMSE = 339 kcal/d; MAPE = 9.4%; MAE = 266 kcal/d.	
Women, 19 years and above	
Inactive	TEE = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight)
Low active	TEE = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight)
Active	TEE = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight)
Very active	TEE = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight)
NOTE: R^2 = 0.71; R^2 adj = 0.70; R^2 shr = 0.70; RMSE = 246 kcal/d; MAPE = 8.7%; MAE = 191 kcal/d.	
Boys, 3–18 years	
Inactive	TEE = – 447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight)
Low active	TEE = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight)
Active	TEE = – 388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight)
Very active	TEE = – 671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight)
NOTE: R^2 = 0.92; R^2 adj = 0.92; R^2 shr = 0.92; RMSE = 259 kcal/d; MAPE = 7.1%; MAE = 163 kcal/d.	

Girls, 3–18 years	
Inactive	TEE = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight)
Low active	TEE = – 297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight)
Active	TEE = – 189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight)
Very active	TEE = – 709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight)
NOTE: R^2 = 0.84; R^2 adj = 0.84; R^2 shr = 0.83; RMSE = 237 kcal/d; MAPE = 8.2%; MAE = 165 kcal/d.	
Boys, 0–2 years	
TEE = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight)	
NOTE: R^2 = 0.83; R^2 adj = 0.83; R^2 shr = 0.83; RMSE = 104 kcal/d; MAPE = 13.6%; MAE = 79 kcal/d	
Girls, 0–2 years	
TEE = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight)	
NOTE: R^2 = 0.83; R^2 adj = 0.83; R^2 shr = 0.83; RMSE = 95 kcal/d; MAPE = 12.8%; MAE = 74 kcal/d.	
Pregnant women in their second and third trimester of pregnancy	
Inactive	TEE = 1,131.20 – (2.04 × age) + (0.34 × height) + (12.15 × weight) + (9.16 × gestation)
Low active	TEE = 693.35 – (2.04 × age) + (5.73 × height) + (10.20 × weight) + (9.16 × gestation)
Active	TEE = – 223.84 – (2.04 × age) + (13.23 × height) + (8.15 × weight) + (9.16 × gestation)
Very active	TEE = – 779.72 – (2.04 × age) + (18.45 × height) + (8.73 × weight) + (9.16 × gestation)
NOTE: R^2 = 0.63; R^2 adj = 0.62; R^2 shr = 0.61; RMSE = 282 kcal/d; MAPE = 8.8%; MAE = 222 kcal/d.	

NOTES: TEE = total energy expenditure; kcal/d = kilocalorie per day; TEE is in kilocalories/day, age is in years, weight is in kilograms, height is in centimeters, and gestation is in weeks. R^2 = R squared; R^2 adj = adjusted R squared; R^2 shr = shrunken R squared; RMSE = root mean squared error; MAPE = mean absolute percentage error; MAE = mean absolute error. RMSE is the same as standard error of the estimate (SEE).

EQUATIONS TO ESTIMATE ENERGY REQUIREMENTS

The EER is used to predict an appropriate energy intake to plan and assess diets for individuals and groups. The EER equations represent the committee's estimates of energy requirements by age/sex, physical activity, and life-stage group. The committee used the TEE equations to develop EER equations by age/sex and life-stage groups for the United States and Canada. The EER equations are shown in Tables S-2 through S-6.

TABLE S-2 Summary Table of EER Equations by Age, Sex, Physical Activity, and Energy Cost of Growth: Children and Adolescents

Age Group	Sex	PAL Category	EER Equation (kcal/d)
0 to 2.99 months	M	—	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 200
	F	—	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 180
3 to 5.99 months	M	—	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 50
	F	—	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 60
6 months to 2.99 years	M	—	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 20
	F	—	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 20/15[a]
3 to 13.99 years	M	Inactive	EER = –447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight) + 20/15/25[b]
		Low active	EER = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight) + 20/15/25
		Active	EER = –388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight) + 20/15/25
		Very active	EER = –671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight) + 20/15/25
	F	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + 15/30[c]
		Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + 15/30
		Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + 15/30
		Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + 15/30

TABLE S-2 Continued

Age Group	Sex	PAL Category	EER Equation (kcal/d)
14 to 18.99 years	M	Inactive	EER = –447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight) + 20
		Low active	EER = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight) + 20
		Active	EER = –388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight) + 20
		Very active	EER = –671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight) + 20
	F	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + 20
		Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + 20
		Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + 20
		Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + 20

NOTES: kcal/d = kilocalories per day; PAL = physical activity level; EER = Estimated Energy Requirement. Age is in years, weight is in kilograms, and height is in centimeters.

[a] Energy cost of growth for girls: 6 to 11.99 months: 20 kcal/d; 12 to 35.99 months: 15 kcal/d.

[b] Energy cost of growth for boys: 3 y: 20 kcal/d; 4 to 8 y: 15 kcal/d; 9 to 13 y: 25 kcal/d.

[c] Energy cost of growth for girls: 3 y: 15 kcal/d; 4 to 8 y: 15 kcal/d; 9 to 13 y: 30 kcal/d.

TABLE S-3 Summary Table of EER Equations Based on TEE Prediction by Age, Sex, and Physical Activity: Adults

Age Group	Sex	PAL Category	EER Equation (kcal/d)
19+ years	M	Inactive	EER = 753.07 – (10.83 × age) + (6.50 × height) + (14.10 × weight)
		Low active	EER = 581.47 – (10.83 × age) + (8.30 × height) + (14.94 × weight)
		Active	EER = 1,004.82 – (10.83 × age) + (6.52 × height) + (15.91 × weight)
		Very active	EER = –517.88 – (10.83 × age) + (15.61 × height) + (19.11 × weight)
	F	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight)
		Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight)

continued

TABLE S-3 Continued

Age Group	Sex	PAL Category	EER Equation (kcal/d)
		Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight)
		Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight)

NOTES: kcal/d = kilocalories per day; PAL = physical activity level; EER = Estimated Energy Requirement; TEE = total energy expenditure. For weight stable adults, EER (kcal/d) = TEE (kcal/d). Age is in years, weight is in kilograms, and height is in centimeters.

TABLE S-4 Summary Table of EER Equations for Pregnant Women During the Second and Third Trimesters of Pregnancy

Life Stage	PAL Category	EER Equation (kcal/day)
2nd and 3rd trimester of pregnancy[a]	Inactive	EER = 1,131.20 – (2.04 × age) + (0.34 × height) + (12.15 × weight) + (9.16 × gestation) + energy deposition
	Low active	EER = 693.35 – (2.04 × age) + (5.73 × height) + (10.20 × weight) + (9.16 × gestation) + energy deposition
	Active	EER = –223.84 – (2.04 × age) + (13.23 × height) + (8.15 × weight) + (9.16 × gestation) + energy deposition
	Very active	EER = –779.72 – (2.04 × age) + (18.45 × height) + (8.73 × weight) + (9.16 × gestation) + energy deposition

NOTES: For pregnancy: EER (kcal/d) = TEE (kcal/d) + energy deposition (kcal/d). Energy deposition/mobilization (kcal/d) estimated for underweight (UW), normal weight (NW), overweight (OW), and obese (OB) pregnant women during the 2nd and 3rd trimesters of pregnancy: + 300 kcal/d for UW; + 200 kcal/d for NW; + 150 kcal/d for OW; –50 kcal/d for OB. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, gestation is in weeks, energy deposition is in kilocalories/day.

[a]For the 1st trimester of pregnancy, the nonpregnant TEE prediction equation should be used. It is assumed that energy deposition/mobilization is negligible and is therefore ignored.

TABLE S-5 Summary Table of EER Equations for Women and Girls Exclusively Breastfeeding 0 to 6 Months Postpartum

Age Group	PAL Category	EER Equation (kcal/day)
Women, 19 years and above	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight) + energy cost of milk production – energy mobilization
	Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight) + energy cost of milk production – energy mobilization
	Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight) + energy cost of milk production – energy mobilization
	Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight) + energy cost of milk production – energy mobilization
Girls, < 19 years	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + energy cost of milk production – energy mobilization
	Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + energy cost of milk production – energy mobilization
	Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + energy cost of milk production – energy mobilization
	Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + energy cost of milk production – energy mobilization

NOTES: For exclusively breastfeeding 0 to 6 months postpartum: EER (kcal/d) = TEE (kcal/d) + energy cost of milk production (kcal/d) – energy mobilization (kcal/d). Energy cost of milk production estimated for women and girls exclusively breastfeeding 0 to 6 months postpartum: 540 kcal/d. Energy mobilization estimated for women and girls exclusively breastfeeding 0 to 6 months postpartum: 140 kcal/d. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, energy cost of milk production is in kilocalories/day, and energy mobilization is in kilocalories/day.

TABLE S-6 Summary Table of EER Equations for Women and Girls Partially Breastfeeding 7 to 12 Months Postpartum

Age Group	PAL Category	EER Equation (kcal/day)
Women, 19 years and above	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight) + energy cost of milk production
	Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight) + energy cost of milk production
	Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight) + energy cost of milk production
	Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight) + energy cost of milk production
Girls, < 19 years	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + energy cost of milk production
	Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + energy cost of milk production
	Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + energy cost of milk production
	Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + energy cost of milk production

NOTES: For partially breastfeeding 7 to 12 months postpartum: EER (kcal/d) = TEE (kcal/d) + energy cost of milk production (kcal/d). Energy cost of milk production estimated for women and girls partially breastfeeding 7 to 12 months postpartum: 380 kcal/d. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, and energy cost of milk production is in kilocalories/day.

ASSESSMENT OF ENERGY INTAKE AND EXPENDITURE AND OUTCOME MEASURES

Part of the committee’s task was to consider the methods used to determine energy intake and expenditure and outcome measures. The committee began by identifying reference data that could be used to show EERs among various age/sex and life-stage groups. The committee also sought data that could be used to assess energy status, expressed as prevalence of underweight, normal weight, overweight, and obesity, among various age/sex/ethnic groups in the United States and Canada. These data included other measures of body weight and energy status that are linked with health risk, such as waist circumference and dual-energy x-ray absorptiometry (DXA) measures. The committee’s findings confirm the high levels of overweight and obesity in both the child and adult populations of the United States and Canada.

The committee further evaluated dietary intake data from U.S. and Canadian national surveys and compared results to the estimated EERs. This involved comparing peer-reviewed literature on reported energy intakes based on 24-hour dietary recalls with objective DLW measures, which showed that DLW was a more accurate measure. This illustrated why assessing reported energy intake is not an appropriate method for determining actual energy intake at the population level. Lastly, the committee reviewed current evidence on the influence of BMI on energy expenditure.

APPLICATIONS OF THE ESTIMATED ENERGY REQUIREMENTS TO DIETARY PLANNING AND ASSESSMENT

The DRIs, including the EER, have primary applications in the planning and assessment of dietary intakes for both individuals and groups, with the overarching goal of achieving intakes that are adequate but not excessive. In contrast to other DRIs, for energy a "safe range of intake" does not apply because intakes above or below requirements lead to either weight gain or loss. Therefore, energy has neither a Recommended Dietary Allowance (RDA) nor a Tolerable Upper Intake Level (UL); rather, the EER equation is used to predict an appropriate energy intake for individuals and groups.

Planning for energy intakes using the EER is a two-step process. The first step is to select the appropriate EER equation to use for the individual or group and calculate the EER, and the second step is to monitor body weight over time—if undesired weight gain or loss occur, adjust the energy intake as needed to maintain the desired weight. A critical element in selecting the appropriate EER equation is identifying the correct PAL category: inactive, low active, active, or very active.

Planning Energy Intakes for Individuals

The EER for an individual is calculated by inserting the person's age, height, and weight into the appropriate EER equation. For example, the EER for a 22-year-old woman who is 165 cm in height, weighs 63 kg, and was determined to have a low active PAL is calculated as follows:

$$\begin{aligned}\text{EER} &= 575.77 - (7.01 \times \text{age in years}) + (6.60 \times \text{height in cm}) \\ &\quad + (12.14 \times \text{weight in kg}) \\ &= 575.77 - (7.01 \times 22) + (6.60 \times 165) + (12.14 \times 63) \\ &= 575.77 - 154.22 + 1{,}089.0 + 764.82 \\ &= 2{,}275 \text{ kcal/day}\end{aligned}$$

In this example, the calculated EER represents the average requirement of women with these values for age, height, weight, and PAL category. Like other nutrients, however, requirements for energy vary among individuals with the same age, height, weight, and PAL category. The extent of variability is indicated by the standard error of the predicted value (SEPV), which reflects how much an individual's requirement may vary from the value predicted by the EER equation. Assuming that this variation is normally distributed, approximately 68 percent of individuals with given characteristics will have an energy requirement within 1 SEPV of the value predicted by the EER equation and almost everyone with those characteristics will have energy requirements within 1.96 SEPV of the value predicted by the equation.

When calculating the EER for the second and third trimesters of pregnancy, a woman's prepregnant BMI and the number of weeks she has been pregnant is needed, along with her current age, height, weight, and PAL category. The EER equation also includes an increment, which varies depending on a woman's prepregnant BMI, for the deposition of new tissue necessary to support the products of conception. Another update to the EER equation was to ensure that, if physical activity changes during pregnancy, the EER will be adjusted to reflect the change. Thus, the appropriate EER equation for pregnancy is based on the woman's current PAL, age, height, weight, and weeks of pregnancy and includes extra calories needed for energy deposition during the second and third trimesters.

To plan for energy intake during lactation, the EER equation for an appropriate PAL category for women 19 years of age and older is used, to which an increment is added. The increments are based on the energy cost of producing milk and energy mobilized among women who are exclusively breastfeeding during the first 6 months of lactation and then only the cost of producing milk for partially breastfeeding beyond 6 months. This additional energy cost assumes a gradual weight loss of 0.64 kg/month in the first 6 months postpartum.

During pregnancy, monitoring weight gain is crucial; energy intake can be adjusted as needed to achieve the appropriate rate and amount of weight gain throughout pregnancy to avoid adverse outcomes for the mother or child. It is also important to monitor the rate of weight loss for the postpartum woman and adjust energy intake as needed or desired to facilitate a quicker return to prepregnancy weight.

Planning Energy Intakes for Groups

Planning energy intake levels for groups is challenging, as group members may vary considerably in terms of age, sex, body size, and physical activity level, and planners may or may not have access to the individual characteristics of group members. As with individuals, the planning process includes selecting the appropriate EER equation, followed by monitoring body weight over time and adjusting the energy content of the food provided as needed. The first step in planning for groups differs from that for individuals in that a reference individual is identified based on median heights and weights of the group members (or if data for group members are not available, based on median height and weight of the appropriate age/sex group among the overall population). Alternatively, if the planner knows that most of the group members are in a specific weight category, EERs may be calculated using reference heights and weights for those in a specific weight category, such as normal weight, overweight, or obese.

The committee identified a number of limitations in the approach to planning energy intakes of groups. While the EER will closely approximate the average energy requirements of the group, it will overestimate or underestimate the requirements of many group members. The consequences differ depending on the extent to which individual group members can choose the amounts of food they receive or whether everyone in the group receives an identical amount of food and whether the planner provides all or just some meals and snacks throughout the day. The risk of weight loss in group members with above-average energy requirements is greatest when everyone receives the same amount of food and the planner provides all meals and snacks; while those with lower-than-average energy requirements may choose not to eat all the food they are served.

Assessing Energy Intakes for Individuals

The calculated EER for an individual has a large confidence interval, so comparing an individual's energy intake to their calculated EER does not indicate whether they are meeting, exceeding, or falling below their actual energy requirement. Overreporting and underreporting occur among most age/sex groups, with underreporting being the most frequent occurrence, the extent of which appears to vary by factors such as age, sex, body weight, and health status. Thus, assessing adequacy of energy intake based on self-reported dietary intake data is not considered accurate. The biological indicator of adequacy for energy (body weight maintenance) is easily measured, however, without need of laboratory assessments. By definition, nongrowing individuals maintaining a stable weight are meeting their energy requirements, while those currently gaining or losing weight are exceeding or falling below their requirements, respectively. For growing children and pregnant women, meeting the energy requirement is reflected by gaining the expected amount of weight over time. Inadequate or excessive intakes in these groups are reflected by failure to gain the expected amount of weight (or in some cases, by weight loss) or gaining excessive amounts of weight, respectively.

Assessing Energy Intakes for Groups

As with individuals, it is not appropriate to use reported energy intake to determine the prevalence of energy inadequacy or excess in a group. For many nutrients, prevalence of inadequacy in a group is estimated by determining the proportion of the group's usual nutrient intake distribution that falls below the Estimated Average Requirement (EAR) (IOM, 2000), but this cannot be done for energy because intakes are highly correlated with requirement and misreporting is prevalent.

Reported energy intakes from national surveys indicate that intakes are generally well below the EER calculated for the group for adults. Further, they are not subdivided by PAL category, as the surveys do not collect data that would permit a PAL category to be determined. Nevertheless, in all cases, the reported median energy intakes were well below the EER. Additionally, the gap between reported intakes and the EER for inactive PAL increased across BMI categories. Systematic misreporting of energy intakes underlies the differences between reported intakes of groups and the EER for the group. Rather than relying on reported energy intakes, the adequacy of a group's energy intake is better determined by assessing its relative weight status.

RISK CHARACTERIZATION AND PUBLIC HEALTH IMPLICATIONS

The committee examined evidence gathered through its umbrella review to assess the relevance, strengths, and limitations for elucidating relationships between a given determinant and a health outcome. Three measures were used as indicators of intake deviations from energy requirements: (1) the association with BMI, (2) the association with weight change, and (3) the association with weight cycling.

Chronic Disease Risk for Overweight and Obesity

Although risk for some chronic disease states may be better predicted by waist circumference, waist–hip ratio, or waist–height ratio, the body of evidence reviewed by the committee indicates a strong relationship between high BMI and functional disabilities, impaired quality of life, serious disease states, and mortality.

Weight Change

Systematic reviews of longitudinal studies examining the association between weight change and chronic disease as well as mortality provided limited evidence of significance for a causal effect of weight change on disease risk and mortality. In one systematic review, weight change measured from childhood to adulthood that included a shift of normal to high weight or excessive weight in both time periods was associated with higher risks of incident cardiovascular disease and hypertension. Evidence for an association of weight change with diabetes is more consistent. Length of follow-up, elimination of preexisting conditions, and whether weight is measured are critical issues to reconcile in this body of literature.

Weight Cycling

Twenty to 55 percent of adults with overweight or obesity have a history of weight cycling, a common outcome among individuals seeking weight loss treatment. The range of consequences of weight cycling on health outcomes, however, have yet to be clarified. Repeated cycles of weight loss and regain have been shown to promote greater subsequent or future weight gain, and this has been hypothesized to occur through the process of adaptive thermogenesis or energy compensation and thus may predispose an individual to greater risk of obesity or increased adiposity as a consequence. Long-term obesity is a concern because of public health implications such as predisposition to risk of numerous chronic disease outcomes.

RESEARCH RECOMMENDATIONS

Factors Affecting Energy Requirements

Data are limited on how variables such as the macronutrient composition of the diet, the gut microbiome, dietary fiber, and genetic factors affect energy requirements at all life stages. This information would be particularly valuable for individuals participating in DLW studies.

To better determine the EER for pregnant women, there is a need for more DLW data and body composition data on pregnant women across all prepregnancy BMI categories. These data could be analyzed specifically to identify the energy needs for pregnant women who have gained within and those who have gained outside the IOM and NRC (2009) gestational weight gain recommendations.

Research Recommendation 1

The committee recommends that the National Institutes of Health (NIH), the U.S. Department of Agriculture (USDA), the Centers for Disease Control and Prevention (CDC), the Department of Veterans Affairs (VA), and Health Canada commit funding to nutrition and kinesiology research that would inform future updates of the Dietary Reference Intakes (DRIs) for energy in all sex and life-stage groups. The committee further recommends research on methodologies to individualize energy requirements when providing precision nutrition care.

Energy Metabolism in Special Population Groups

Energy metabolism data are sparse for diverse racial/ethnic groups, including indigenous populations in the United States and Canada. Evidence on factors that affect energy metabolism and energy requirements in diverse populations is also lacking. Further, the effect of sarcopenic obesity on energy requirements is not well understood, nor is energy balance, energy expenditure, and energy compensation in individuals with BMI ≥ 50. Additionally, data from DLW studies are lacking for certain life-stage groups, and at various BMI levels.

Given the increasing prevalence of chronic disease and other diet-related risk factors across the U.S. and Canadian populations, evidence is needed on medications that affect energy metabolism, and on how medications and procedures such as bariatric surgery affect energy metabolism, especially TEE.

Research Recommendation 2

The committee recommends that NIH, USDA, CDC, VA, and Health Canada commit funding to nutrition research that would inform future updates of the DRIs in diverse populations, including infants, children, adolescents, the oldest old, lactating women, individuals taking medications, and individuals at higher body mass index (BMI) levels.

Weight Change and Energy Metabolism

There is insufficient evidence on defining a weight cycle and determining what frequency, amount, and duration of cycling indicates a significant effect on energy metabolism. In addition, reporting on how weight change is measured is inconsistent, and information on population characteristics and research methodologies relating to the measurement of body weight are inadequately reported in many research articles.

Research Recommendation 3

The committee recommends that investigators studying energy balance and national health surveillance monitoring provide participants' rationales for weight gain or weight loss. In addition, published research reports should indicate whether weight change was measured or self-reported. Nutrition and kinesiology researchers should also use accepted definitions that differentiate basal and resting metabolic rate to standardize terminology in reporting study findings.

Research Recommendation 4

The committee further recommends that research agencies develop a checklist of quality factors (to guide study designs and protocols, and to evaluate study quality) that are relevant to evaluating energy intake imbalances and to relating intake imbalances to health outcomes. Journal editors should require documentation from authors to show that articles accepted for publication have met quality factors for assessing energy intake imbalances.

Application of the EER to Individuals and Population Groups

To support the application of this report's recommendations and their translation to population-level survey data, research is needed on the relationship between TEE and PAL categories using metrics that define physical activity intensity and duration. Because of the complexity in factors associated with selecting a PAL category and calculating the EER, there is potential for error in calculation of the EER owing to misclassification.

Research Recommendation 5

The committee recommends that USDA, the U.S. Food and Drug Administration, NIH, and Health Canada commit funding to develop an app to facilitate calculations of EERs for specific life-stage groups to ensure the wide dissemination and appropriate application of the new EERs. Additionally, CDC

and Canada's Health Statistics agencies should incorporate into their national health surveys measures of physical activity that are compatible with the physical activity level (PAL) categories needed to calculate EERs. Those U.S. and Canadian agencies that fund research to support public health initiatives should invest in development and validation of measures of physical activity that can be used in public health and research contexts.

REFERENCES

IOM (Institute of Medicine). 2000. *Dietary Reference Intakes: Applications in dietary assessment.* Washington, DC: National Academy Press. https://doi.org/10.17226/9956.

IOM. 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids.* Washington, DC: The National Academies Press.

IOM and NRC (National Research Council). 2009. *Weight gain during pregnancy: Reexamining the guidelines.* Washington, DC: The National Academies Press.

1

Introduction

ENERGY INTAKE AND EXPENDITURE IN HUMANS

In nutrition, energy balance is the difference between the amount of energy consumed through the diet and the amount required to sustain the body's functions, such as respiration, circulation, metabolism, and physical activity. Overconsumption of dietary energy that is not matched by increased physical activity energy expenditure can result in weight gain. Similarly, underconsumption of dietary energy without a reduction in physical activity energy expenditure can result in weight loss. Although fluctuation in daily energy intake is common, individual responses to energy balance and body weight are variable

All energy supplied by foods derives from consumption of macronutrients: carbohydrates, fats, protein, alcohol, and to a lesser extent, polyols, organic acids, and novel compounds. A high-level view of how food energy flows through the body is shown in Figure 1-1. Energy remaining after accounting for the losses shown in the first two steps of the figure is referred to as metabolizable energy, which is defined as the "amount of energy available for total (whole body) heat production at nitrogen and energy balance" (Livesey, 2001, p. 283). After this point, additional energy is used for the metabolic processes of digestion, absorption, and intermediary metabolism, which is measured as heat production and commonly referred to as the thermic effect of food (TEF) or diet-induced thermogenesis (DIT). While there has been an evolution of the food energy conversion factors over the years, the Atwater general factor is typically used for its simplicity. It uses a single factor for each macro-

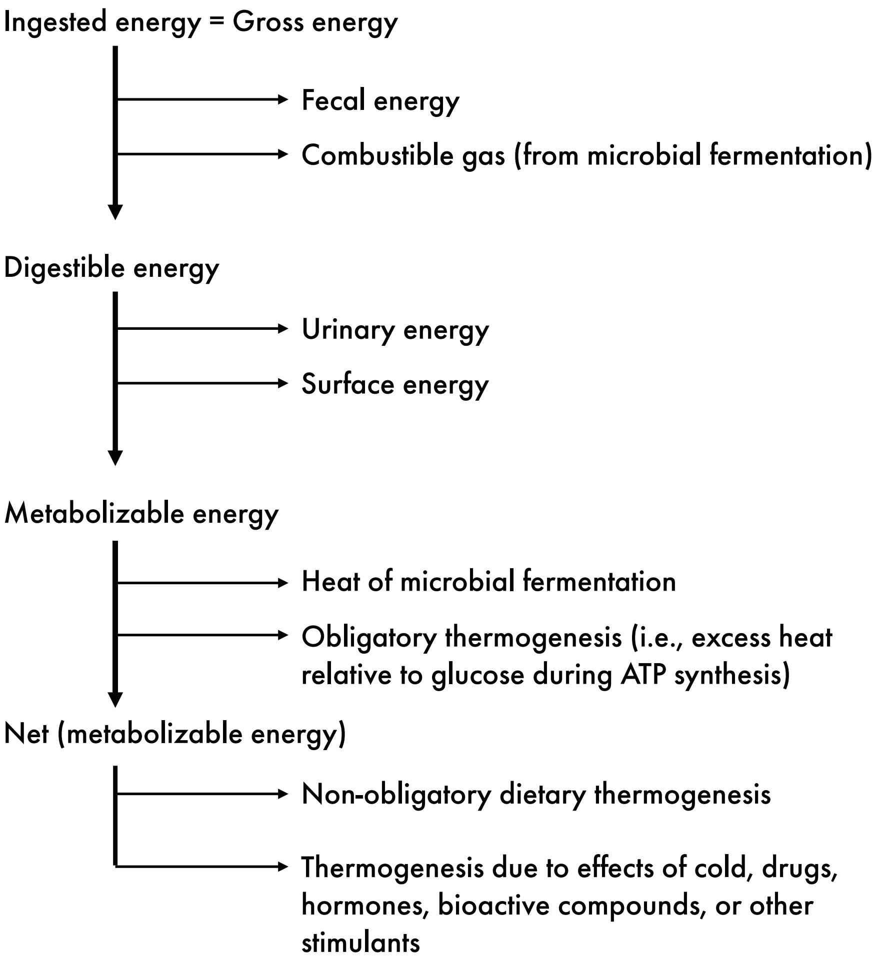

FIGURE 1-1 Overview of food energy flow through the body for maintenance of energy balance.
SOURCE: Adapted from: FAO (Food and Agriculture Organization of the United Nations). 2003. *Food energy - Methods of analysis and conversion factors. Report of a technical workshop. Rome, 3-6 December 2002.* FAO Food and Nutrition Paper 77. https://www.fao.org/3/y5022e/y5022e00.htm#Contents.

nutrient and alcohol as follows: 4 kcal/g for carbohydrate and protein, 9 kcal/g for fat, and 7 kcal/g for alcohol.

Over the past few decades, many individuals residing in the United States and Canada have experienced an imbalance in their energy input and output such that weight status has trended toward increased overweight and obesity across demographic groups. Since 2016, the National Health and Nutrition Examination Survey (NHANES), the Canadian Community Health Survey (CCHS), and the Canadian Health Measures Survey (CHMS) have indicated that the combined prevalence of overweight and obesity among U.S. adults aged 20 years and over is 73.6 percent and 63.1 percent among Canadian adults aged 18 and over (Fryar et al., 2020; Statistics Canada, 2019). This trend of higher weight status is especially challenging for younger individuals, who are at risk of living with this condition over the long term. Results from the NHANES 2017–2020 estimate that prevalence of obesity among U.S. children aged 2 to 19 years is 19.7 percent (Stierman et al., 2021).

These trends in overweight and obesity have been identified using body mass index (BMI) as cut points. BMI is defined as body weight in kilograms divided by the square of height in meters. The National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC) guidelines use the original World Health Organization (WHO) cut points to define (for adults) underweight as BMI < 18.5, normal weight as BMI 18.5–24.9, overweight as BMI 25.0–29.9, and obese as BMI ≥ 30 (CDC, 2022; NIH, 2021; WHO, 2010).

An update of the WHO classifications added categories to identify severe underweight (BMI < 16.5) and to further define obesity risk in adults as class I (BMI 30.0–34.9), class II (BMI 35.0–39.9), and class III (BMI ≥ 40.0) (WHO Expert Consultation, 2004). In both clinical and community settings, calculation of BMI remains the easiest and most readily accessible tool for identifying individuals at risk of adverse health outcomes related to being overweight or underweight (Gonzalez et al., 2017). It is important to note that BMI is an insensitive measure because it assumes that there is an optimal weight range, regardless of body composition or association of BMI with morbidities and mortality. BMI does not account for interindividual variability by age, sex, ethnicity, or health status (Gonzalez et al., 2017; Pasco et al., 2012).

The need to reexamine the Dietary References Intakes (DRIs) for energy, last updated in 2005 (IOM, 2002/2005), arose primarily from two factors. First is the continued rise in BMI-defined prevalences of overweight and obesity. Second, new scientific evidence has advanced knowledge about the energy requirements of individuals to balance energy expenditure and promote a normal weight status and reduce risk of chronic disease. This report examines that evidence and provides updated estimated energy requirements for the United States and Canada by age, sex, and life-stage group.

BACKGROUND FOR THE STUDY

History and Changing Nature of the DRIs

The DRIs are a set of evidence-based nutrient reference intake values for a range of age, sex, and life-stage groups that are used in the United States and Canada for planning and assessing diets of individuals and groups. The DRIs also serve as reference values in design and evaluation of research studies; development of dietary guidelines, food guides, and product labeling; planning and monitoring of nutrition-related public health programs and initiatives including military nutrition standards; and nutrition counseling and education programs.

The current DRIs are an expansion of the original intake value, the Recommended Dietary Allowance (RDA), which served as the nutrient intake standard for the U.S. population from 1941 through 1989. For all nutrients other than energy, DRI values may include the Estimated Average Intake (EAR), the Recommended Dietary Allowance (RDA), the Average Intake (AI), and, when applicable, the Tolerable Upper Intake Level (UL). Acceptable Macronutrient Distribution Ranges (AMDR) were developed to provide guidance on the relative ranges of energy intakes from carbohydrates, proteins, and fats. The AMDR was intended to provide guidance on intake ranges of energy nutrients associated with reduced risk of chronic diseases while also ensuring that the intakes of essential amino acids and fatty acids and total protein could be met. More recently, the Chronic Disease Risk Reduction Intake (CDRR) was added for evaluating the relationship of nutrients to chronic disease risk. Table 1-1 provides definitions of the current DRI values.

For energy, the DRI value is expressed as the estimated energy requirement (EER). This value is unique among DRIs because energy intakes outside the EER would be expected to result in weight gain or loss rather than nutrient deficiency or toxicity. The EER as originally defined for DRIs is a level of energy intake from food that is predicted to balance energy expenditure relative to an individual's body size and composition and level of physical activity that is consistent with long-term health, and that allows for the maintenance of normal physical activity. In children and pregnant or lactating females, the EER includes energy needs associated with tissue accretion or production of milk at rates consistent with maintaining health (IOM, 2002/2005).

Since publication of the first DRIs for macronutrients (IOM, 2002/2005), considerable attention has focused on developing more robust and transparent approaches to the DRI process, such as the use of systematic reviews rather than narrative reviews of the evidence. In 2007, the Institute of Medicine (IOM) held a workshop to identify issues important for enhancing the process of DRI development. This workshop

TABLE 1-1 Definitions of Dietary Reference Intake (DRI) Values

DRI	Definition
Estimated Energy Requirement (EER)	The average dietary energy intake that is predicted to maintain energy balance in an adult of a defined age, sex, weight, height, and level of physical activity
Estimated Average Requirement (EAR)	The average daily nutrient intake estimated to meet the requirement of half the individuals in a particular sex and life-stage group
Recommended Dietary Allowance (RDA)	The average daily dietary nutrient intake sufficient to meet the nutrient requirements of nearly all (97–98%) individuals in a particular sex and life-stage group
Adequate Intake (AI)	The recommended average daily intake based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of individuals that are assumed to be adequate—used when an RDA cannot be determined
Tolerable Upper Intake Level (UL)	The highest average daily nutrient intake that is likely to pose no risk of adverse health effects to almost all individuals in the general population; as intake increases above the UL, the potential risk of adverse effects may increase
Acceptable Macronutrient Distribution Ranges (AMDR)	A range of usual intakes for a macronutrient that is associated with a reduced risk of chronic disease while providing adequate intakes of essential nutrients; an AMDR is expressed as a percentage of total energy intake
Chronic Disease Risk Reduction (CDRR)	DRIs based on chronic disease reference values

SOURCES: IOM, 2002/2005; NASEM, 2017.

highlighted the many challenges related to incorporating chronic disease endpoints into the DRI process. The workshop summary, *The Development of DRIs 1994–2004: Lessons Learned and New Challenges*, helped advance some of these issues, including a proposed overall organizing framework, but scientific challenges related to the use of chronic disease endpoints remained (IOM, 2008).

In 2015, the Joint U.S. and Canadian Federal DRI Working Group (federal working group) convened a public workshop and published its report, *Options for Basing Dietary Reference Intakes (DRIs) on Chronic Disease Endpoints: Report from a Joint U.S./Canadian-Sponsored Working Group* (Yetley et al., 2017). A committee convened by the National Academies of Sciences, Engineering, and Medicine (the National Academies) subsequently used the federal working group's report as a resource for a consensus study. The committee's report, *Guiding Principles for Developing Dietary Reference Intakes Based on Chronic Disease,* provided guidance for facilitating and standardizing the use of chronic disease endpoints in future DRI reviews (NASEM, 2017).

As noted above, prior to the publication of the CDRR, the AMDR was calculated as an intake amount needed to achieve energy balance to reduce risk of overweight or obesity. When intakes of macronutrients fall above or below the AMDR, the risk for the development of chronic disease (e.g., diabetes, cardiovascular disease, cancer) appears to increase. There is emerging evidence about the role of factors influencing energy balance in chronic disease risk that will influence future DRI reviews linked to the EER, the AMDR, and energy intake recommendations. Notably, digestible dietary fiber has been identified as the primary source of energy needed to support gut microbiota. Insufficient fiber intake can lead to the depletion of human gut microbiota diversity and beneficial metabolites. Inadequate intake of digestible fiber may increase risk of adverse health outcomes, particularly metabolic syndrome and obesity-related chronic disease (Hervik and Svihus, 2019).

In response to the challenges identified in these reports and at the request of the federal working group, the National Academies convened an expert panel to explore these issues in depth. In 2020, it held a series of internal expert meetings to develop a strategic approach to review the DRIs for all macronutrients and energy. The committee identified and invited subject-matter experts to participate in open session discussions with the committee on the DRI conceptual framework, the state of the science relevant to the review of macronutrients, and the process for approaching a new DRI review. The invited experts discussed using an umbrella literature review (a review of existing systematic reviews), with additional studies included when necessary for identifying new data related to DRIs for energy and macronutrients and chronic disease endpoints. The invited experts also discussed prioritization criteria, including significant new data, implications for public health, current controversies related to macronutrients, and the usability of current DRIs for macronutrients and energy. Lastly, they identified first steps in a prioritization process to ascertain user needs and consult with subject-matter experts to determine the status of DRI-relevant data.

Updating and Revising the 2005 DRIs for Energy

In the IOM (2002/2005) report, EER prediction equations for free-living individuals with normal weight were developed from data on total daily energy expenditure measured by the doubly labeled water (DLW) technique. As identified in the above-mentioned expert meeting discussions, an expanded DLW database has since been assembled by Speakman and colleagues (2019). The DLW database, hosted by the International Atomic Energy Agency (IAEA), consists of 6,621 DLW measurements recorded since the early 1980s across 23 countries. These cumulative data provide an opportunity to expand and fill gaps in the original DLW database as well as reevaluate the equations used to derive the EER. A specific advantage of using the IAEA DLW database is that it provides an estimate of total energy expenditure over a period of several days, enabling adjustment for reducing the effect of day-to-day variability in energy intake and physical activity.

Integral to the calculation of EERs is the delineation of energy needs by physical activity level (PAL). Recent evidence indicates that the PAL coefficient is not constant but varies significantly across age groups, particularly during the first 20 years of life. The incorporation of newer DLW and outcome data in the IAEA database may better define physical activity levels across age/sex groups relative to body weight, fitness, and other aspects of age and sex groups.

The range of new evidence published since the first DRI review of energy and macronutrients (IOM, 2002/2005) provides a compelling reason to reevaluate the factors that affect derivation of the EER to determine human requirements for energy intake and expenditure and to assess the role of energy in reducing the risk of chronic disease. Further, evidence of changes in population health (i.e., increased prevalence of obesity and risk of chronic disease) necessitated reconsideration of the DRI population in order to be more inclusive. The committee hereinafter defines the DRI population as the general population, rather than the generally healthy population. This reevaluation is best done in advance of performing new DRI reviews of dietary macronutrients.

THE COMMITTEE'S TASK AND APPROACH

In response to new and emerging evidence related to factors affecting derivation of the EER, the role of energy in supporting metabolic functions, and energy's relationship to the risk of chronic disease, the federal working group asked the National Academies to convene a consensus committee to undertake a review of the Dietary Reference Intakes for Energy (Box 1-1). Specifically, the committee was asked to assess the human requirements for energy intake and expenditure and to consider age, sex, body size, body composition, level of physical activity, race/ethnicity, and other factors that may be warranted based on available data. Other significant variables for consideration include energy for growth and maturation and to support pregnancy, energy needs postpartum, energy intake amounts to achieve and maintain weight loss or weight gain, energy requirements to support recovery from disease and treatments or interventions such as surgery, and the health consequences of chronic overnutrition or undernutrition across the life span.

BOX 1-1
Statement of Task

An ad hoc committee will be convened under the auspices of the National Academies of Sciences, Engineering, and Medicine to assess human requirements for energy intake (including the contribution of alcohol and gut microbiota digestible dietary fiber) and energy expenditure. The review will consider age, sex, body size, body composition, level of physical activity, and race/ethnicity, along with other factors that may be warranted based on available data. The committee will consider other significant variables, including energy needed for growth and maturation and to support pregnancy, energy needs postpartum, amounts to achieve and maintain weight loss or weight gain, requirements to support recovery from disease and treatments or interventions such as surgery, and the health consequences of chronic overnutrition or undernutrition across the life span. Special consideration will be given to each age/sex group across the life span. The committee will produce a report that will be reviewed in accordance with institutional requirements and will include the following:

1. A review of the components of energy expenditure in consideration of appropriate methods of assessment.
2. A review of the evidence on energy requirements specific to age, sex, body size and body composition, physiological state (e.g., pregnancy, lactation, and menopause), and level of physical activity consistent with good health. Where data allow, the committee will explore the impact of common physiological states such as underweight or overweight and obesity, and prediabetes/diabetes on energy requirements.
3. A review of the evidence for relationships between energy balance/imbalance states with risk of chronic disease and other health outcomes.
4. Consideration of a range of evidence sources, including the International Atomic Energy Agency doubly labeled water database. This will require data analysis to validate and/or update the Estimated Energy Requirement (EER) equations.
5. Summary tables of included studies and/or databases based on relevant indicators used to assess Dietary Reference Intakes (DRIs) that include, but are not limited to:
    a. Study design;
    b. Setting;
    c. Participant age, sex, or life-stage group;
    d. Physiological state;
    e Sample size, intervention or exposure, methods used to determine energy intake and output and outcome measures; and
    f. A description of the statistical analysis used by investigators.

BOX 1-1 Continued

6. An updated EER, as appropriate, for each age, sex, and life-stage group, using the risk assessment approach as described in the DRI organizing framework.
7. Identification of research gaps to address the uncertainties identified in the process of deriving the reference values and evaluation of their public health implications.

In response to the sponsor's request, the Health and Medicine Division of the National Academies established a committee with expertise in the following:

- Energy metabolism across the life span, including pregnancy, lactation, and menopause;
- Physical activity;
- Human nutrition across the life span;
- Clinical trials, including design and conduct of diet interventions;
- Methods in energy metabolism and body composition;
- Systematic review methodology, including quality and risk-of-bias assessment;
- Statistics, modeling, and analysis methods;
- Application of the DRI framework; and
- Use of doubly labeled water data.

Biographical sketches of the committee members are provided in Appendix B.

The committee began by gathering evidence from several sources, which involved conducting an umbrella review of systematic reviews and gathering information during open meetings that it convened with subject-matter experts (see Chapter 3 and Appendix C). The committee also engaged expert consultants and requested data analyses from CDC and Statistics Canada.

The committee also participated in open-session discussions held by the Standing Committee for the Review of the Dietary Reference Intakes Framework (the standing committee) to discuss questions about defining the DRI population. In a subsequent open session, the standing committee reported its guidance on this question to the federal working group and the Committee to Review the DRIs for Energy (i.e., the present committee). In a letter report to the federal working group, the standing committee noted that the report, *Guiding Principles for Developing Dietary Reference Intakes Based on Chronic Disease* (NASEM, 2017) stated that the general U.S. and Canadian populations included individuals with obesity and other chronic conditions such as hypertension or diabetes, as well as individuals at risk of chronic disease who do not meet DRI exclusion criteria where they exist. Consistent with the findings in the National Academies' report (NASEM, 2017), the standing committee concluded:

> Individuals with chronic diseases or chronic disease risk factors should be considered as part of the general population unless there is an effect of the disease and/or medications on nutritional status that would alter normal physiologic requirements. (NASEM, 2022, p.15)

Based on the totality of evidence gathered, open-session discussions with subject-matter experts, guidance from the standing committee, and its deliberations, the committee formulated an approach to address its work and derive the findings, conclusions, and recommendations that are presented in this report.

ORGANIZATION OF THE REPORT

This report is organized into nine chapters. This first chapter describes the background for the study, the statement of task, and the study approach. Chapter 2 provides an overview of the DRI process. Chapter 3 describes the committee's methodological approach to its task. Chapter 4 reviews metabolic factors that affect energy expenditure and requirements. Chapter 5 presents the prediction equations for estimated energy requirements that the committee developed. Chapter 6 describes dietary intake assessment and body composition from national surveys and compares them between U.S. and Canadian populations. Chapter 7 illustrates applications of the DRIs to assess and plan energy intakes for individuals and groups. Chapter 8 characterizes relative risk and discusses public health implications of inadequate and excessive energy intakes and expenditure. Chapter 9 presents research gaps and recommendations.

REFERENCES

CDC (Centers for Disease Control and Prevention). 2022. *Defining adult overweight & obesity*. https://www.cdc.gov/obesity/basics/adult-defining.html (accessed November 23, 2022).

Fryar, C. D., M. D. Carroll, and J. Afful. 2020. Prevalence of overweight, obesity, and severe obesity among children and adolescents aged 2–19 years: United States, 1963–1965 through 2017–2018. NCHS Health E-Stats.

Gonzalez, M. C., M. Correia, and S. B. Heymsfield. 2017. A requiem for BMI in the clinical setting. *Current Opinion in Clinical Nutrition and Metabolic Care* 20(5):314-321.

Hervik, A. K., and B. Svihus. 2019. The role of fiber in energy balance. *Journal of Nutrition and Metabolism* 2019:4983657.

IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press.

IOM. 2008. *The development of DRIs 1994-2004: Lessons learned and new challenges: Workshop summary*. Washington, DC: The National Academies Press.

Livesey, G. 2001. A perspective on food energy standards for nutrition labelling. *British Journal of Nutrition* 85(3):271-287.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2017. *Guiding principles for developing Dietary Reference Intakes based on chronic disease*. Washington, DC: The National Academies Press.

NASEM. 2022. *Defining populations for Dietary Reference Intake recommendations: A letter report*. Washington, DC: The National Academies Press.

NIH (National Institutes of Health). 2021. *How are obesity & overweight diagnosed?* https://www.nichd.nih.gov/health/topics/obesity/conditioninfo/diagnosed (accessed November 23, 2022).

Pasco, J. A., G. C. Nicholson, S. L. Brennan, and M. A. Kotowicz. 2012. Prevalence of obesity and the relationship between the body mass index and body fat: Cross-sectional, population-based data. *PloS One* 7(1):e29580.

Speakman, J. R., H. Pontzer, J. Rood, H. Sagayama, D. A. Schoeller, K. R. Westerterp, W. W. Wong, Y. Yamada, C. Loechl, and A. J. Murphy-Alford. 2019. The International Atomic Energy Agency international doubly labelled water database: Aims, scope and procedures. *Annals of Nutrition and Metabolism* 75(2):114-118.

Statistics Canada. 2019. *Health fact sheets: Overweight and obese adults, 2018*. https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/article/00005-eng.htm (accessed September 30, 2022).

Stierman, B., J. Afful, M. D. Carroll, T.-C. Chen, O. Davy, S. Fink, C. D. Fryar, Q. Gu, C. M. Hales, J. P. Hughes, Y. Ostchega, R. J. Storandt, and L. J. Akinbami. 2021. National Health and Nutrition Examination Survey 2017–March 2020 prepandemic data files development of files and prevalence estimates for selected health outcomes. *National Health Statistics Reports* 158.

WHO (World Health Organization). 2010. *A healthy lifestyle - WHO recommendations*. https://www.who.int/europe/news-room/fact-sheets/item/a-healthy-lifestyle---who-recommendations (accessed November 23, 2022).

WHO Expert Consultation. 2004. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 363(9403):157-163.

Yetley, E. A., A. J. MacFarlane, L. S. Greene-Finestone, C. Garza, J. D. Ard, S. A. Atkinson, D. M. Bier, A. L. Carriquiry, W. R. Harlan, D. Hattis, J. C. King, D. Krewski, D. L. O'Connor, R. L. Prentice, J. V. Rodricks, and G. A. Wells. 2017. Options for basing Dietary Reference Intakes (DRIs) on chronic disease endpoints: Report from a joint US-/Canadian-sponsored working group. *American Journal of Clinical Nutrition* 105(1):249S-285S.

2

Overview of the DRI Process

OVERVIEW OF THE DIETARY REFERENCE INTAKES

The Dietary Reference Intakes (DRIs) are a set of reference values that encompass a safe range of intake and provide recommended nutrient intakes for the United States and Canada. The DRI concept developed from discussions about how future Recommended Dietary Allowances (RDAs) should be revised. This issue was covered during the 1993 workshop *How Should the RDAs Be Revised* (IOM, 1994), by the UK Committee on Medical Aspects of Food Policy (COMA, 1991), and as part of a statistical probability concept for nutrient adequacy developed by George Beaton (Beaton, 1991).

The DRI concept offered a new approach that extended nutrient intake recommendations beyond the goal of nutritional adequacy and the prevention of deficiency disease to include public health concerns about chronic disease and overconsumption. This concept:

- Applies a model based on probability and risk to derive a panel of reference values;
- Sets a safe upper intake level to reduce the risk of adverse health effects related to overconsumption of a nutrient; and
- Considers the potential role for nutrients or other food substances in reducing the risk of chronic disease.

Most of the first DRI values were based on biological indicators related to inadequate intakes of nutrients. In recent decades, concern about nutritional deficiency disease within population groups has been replaced with concern about the role of diet on the risk of chronic disease. Weight gain occurs when energy intake exceeds energy expenditure. Such long-term energy intake imbalances are one type of dietary imbalance associated with the risk of chronic diseases. In response, as DRI nutrients have undergone review, the derivation of DRI values has evolved to include consideration of chronic disease risk reduction.

THE DRI ORGANIZING FRAMEWORK

The concept of a DRI organizing framework was introduced at a 2007 workshop, *The Development of DRIs 1994–2004: Lessons Learned and New Challenges* (IOM, 2008). The framework includes the need for a science base that not only addresses information needs in a way that allows for integration into program and policy initiatives but that also presents information in a predictable format so users can easily find topics of particular interest. This requires a standardized format with transparency and documentation of decision making throughout the organizing process.

The framework is adapted from guidance for organizing scientific deliberations to assess DRI components in a way that is useful to sponsors and maintains the scientific integrity of the assessment process (NRC, 1983). The core concepts of the framework relevant to energy are that (1) an incomplete evidence base is expected in a DRI review and uncertainties need to be dealt with by documentation and the use of scientific judgment and (2) the needs of users of the DRIs are a key component of the framework.

The first step in the framework, literature reviews and interpretation, is used to identify and assess indicators of nutrient adequacy or toxicity across age and sex groups in the population. This step includes a review and synthesis of evidence on relevant health outcomes. The strength and quality of the evidence is critical to establishing a rigorous evidence base to support the identification and assessment of indicators of both adequacy and excess.

For energy, doubly labeled water (DLW) databases were selected as the primary evidence base for estimating energy requirement equations. An umbrella review of systematic reviews was used as a source of evidence to understand relationships between energy intake and health outcomes.

The second step in the organizing framework is to identify intake–response data for the nutrient or outcome of interest and to use these data to derive DRI reference values for the DRI life-stage groups. For energy, the Estimated Energy Requirement (EER) is the DRI value. It is derived from well-controlled studies using DLW in which the energy expenditure of individuals is determined.

The third step in the framework is intake assessment. In this step, population-based intake data and/or biological indicators of nutrient status are used to assess intake adequacy or inadequate or excessive exposure levels for a nutrient. National surveys or other large population databases are generally used to obtain population-based intake data.

The last step in the framework considers the public health consequences of either not meeting or exceeding a recommended intake. This includes determining how characteristics unique to a population age/sex group, such as body size, lifestyle, environment, or other factors, could influence nutrient requirements for that group. This DRI organizing framework provides a systematic approach to deriving the DRIs. Further, it supports documentation of the strength and sufficiency of the evidence, enhances transparency, and allows for incorporation of new and emerging scientific tools into the process (IOM, 2011; NASEM, 2019).

A proposed analytic approach to implementing the framework described the link between nutrient exposure and clinical or disease outcome for which a strength of association could be defined. In this model, if a strong evidence base for the clinical or disease outcome is lacking, an indicator marker and/or surrogate marker could be identified that best predicted the clinical outcome (Russell et al., 2009). For example, bone growth is a surrogate marker for phosphorus status. Body weight is an indicator of energy intake balances or imbalances.

When the DRIs for calcium and vitamin D and for sodium and potassium were updated in 2011 and 2019, respectively, the DRI framework was revised to provide a more rigorous and transparent approach to deriving DRI values (IOM, 2011; NASEM, 2019). Specifically, the framework was modified to (1) ensure greater transparency in the decision-making process and (2) provide options for decision making when data needed to support such decisions are limited (i.e., in conditions of uncertainty).

Systematic evidence reviews were introduced in the updated review of DRIs for calcium and vitamin D to provide a rigorous, transparent, and reproducible approach to establishing an evidence base from which to derive DRI values. The systematic review process for DRIs for calcium and vitamin D was refined to include risk-of-bias assessment and the Grading of Recommendations, Assessment, Development and Evaluations (GRADE)[1] system to assess evidence quality. In addition, a formalized approach to identifying an intake range or target goal for reducing risk of chronic disease was introduced with the DRIs for sodium and potassium. This resulted in a new DRI value—the Chronic Disease Risk Reduction (CDRR) value (Table 1-1).

[1] https://www.gradeworkinggroup.org/ (accessed November 11, 2022).

These revisions to the DRI organizing framework have increased the scientific rigor and transparency of the process for deriving reference values. However, despite the additional steps to the framework, absolute certainty does not exist in terms of the state of the science or the strength of evidence to support decision making. When evidence is limited and a lack of guidance could have implications for public health, an informed scientific judgment grounded in transparent and judicious documentation becomes necessary.

ADAPTING THE DRI ORGANIZING FRAMEWORK TO ENERGY

As noted above, the core statistical concept on which the Estimated Average Requirements (EARs) and RDAs are based is a distribution of requirements, meaning a variability in requirements among individuals in a given age/sex group. The EAR is the average intake requirement that meets the requirements of 50 percent of individuals in an age/sex group. The RDA represents intakes that meet or exceed the requirement for 97.5 percent of that group. For most nutrients, the requirements are normally distributed so that the RDA represents 2 standard deviations above the average requirement. Observed intakes for population groups also have distributions. These two separate distributions need to be taken into account when evaluating the adequacy of, or planning for, group or individual intakes.

For all nutrients except for energy, the adequacy of a group's intake for a given nutrient can be evaluated by comparing the usual mean intake of that group to the mean requirement for that group (i.e., the EAR). The prevalence of nutrient inadequacy is estimated as the proportion of the age/sex group with usual intakes below the EAR (IOM, 2000). For individuals, usual intake above the EAR is assumed to be adequate. These quantitative relationships are not directly applicable to energy. While the EAR is the midpoint of the distribution of requirements of a broad age/sex group, the EER is an estimate of the midpoint of a range of requirements that applies to individuals of the same sex, age, height, weight and physical activity level (PAL) category. Furthermore, because energy requirements and intakes are correlated, the prevalence of inadequacy cannot be estimated by determining the proportion with self-reported intakes below the EER. Additionally, unlike other nutrients, the energy requirement distribution does not relate to any other DRI value, such as RDA or Tolerable Upper Intake Level (UL), which do not exist for energy.

For most nutrients, intake–response assessments are used to identify the EAR for a DRI age/sex group, and data on variability are considered to establish the RDA at an intake level that meets or exceeds the needs of almost all individuals in that group. Although consuming an intake level at or above the RDA exceeds the requirements of almost everyone, no risk occurs unless the intake level exceeds the UL. However, this approach is not appropriate for energy, as there are adverse consequences (e.g., weight gain) for individuals whose energy intake exceeds their energy expenditure (i.e., their requirement).

It is also not useful to compare an individual's self-reported energy intake with a calculated expenditure owing to bias in self-reported intake data, as well as the inherent variability in energy expenditure among individuals with similar characteristics. Rather, weight is frequently used as an indicator of the relationship between energy intake and energy expenditure. Body mass index (BMI) is then calculated to screen and categorize individuals and groups. BMI values outside of a defined normal range serve as an indicator of overconsumption or underconsumption of energy and can be used in calculating the EER for various age/sex groups (see Chapter 5). An additional complication is that energy balance is now known to be moderated by diet-related elements other than carbohydrate, protein, fat, and alcohol, namely the microbiome and dietary fiber (see Chapter 4 for factors affecting energy expenditure). Because the DRI organizing framework had not been developed when the first DRIs for energy were established, this committee had the challenge of developing a framework that was responsive to and appropriate for current topics and key areas relevant to energy.

REFERENCES

Beaton, G. H. 1991. Human nutrient requirement estimates. *Food, Nutrition, and Agriculture* 2/3.

COMA (Committee on Medical Aspects of Food Policy). 1991. *Dietary Reference Values for food energy and nutrients for the United Kingdom: Report of the panel on Dietary Reference Values of the Committee on Medical Aspects of Food Policy*. London, UK: Department for Health under license from the Controller of Her Majesty's Stationery Office.

IOM (Institute of Medicine). 1994. *How should the Recommended Dietary Allowances be revised?* Washington, DC: The National Academies Press.

IOM. 2000. *Dietary Reference Intakes: Applications in dietary assessment*. Washington, DC: National Academy Press. https://doi.org/10.17226/9956.

IOM. 2008. *The development of DRIs 1994–2004: Lessons learned and new challenges: Workshop summary*. Washington, DC: The National Academies Press.

IOM. 2011. *Dietary Reference Intakes for calcium and vitamin D*. Washington, DC: The National Academies Press.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2019. *Dietary Reference Intakes for sodium and potassium*. Washington, DC: The National Academies Press.

NRC (National Research Council). 1983. *Risk assessment in the federal government: Managing the process*. Washington, DC: National Academy Press.

Russell, R., M. Chung, E. M. Balk, S. Atkinson, E. L. Giovannucci, S. Ip, A. H. Lichtenstein, S. T. Mayne, G. Raman, A. C. Ross, T. A. Trikalinos, K. P. West, Jr., and J. Lau. 2009. Opportunities and challenges in conducting systematic reviews to support the development of nutrient reference values: Vitamin A as an example. *American Journal of Clinical Nutrition* 89(3):728-733.

3

Methodological Approach to Gathering Evidence

The committee's approach to gathering evidence since the first Dietary Reference Intakes (DRIs) for energy published in 2005 was to conduct an umbrella review—a review of existing systematic reviews relevant to the questions in the statement of task. In the absence of a *de novo* systematic review relevant to the study task, the committee identified topics considered to be of highest priority and carried out the umbrella review supplemented with search terms to identify publications of randomized controlled trials and prospective longitudinal trials from the peer-reviewed published literature. This evidence-gathering approach differs from the approaches used for the two previous DRI updates (i.e., vitamin D and calcium; sodium and potassium), which included new or updated existing systematic reviews as the primary evidence to support committee deliberations, and it differs from the narrative literature review used in the first DRIs for energy, which the committee determined would not support the range or the quality of evidence needed to carry out its task.

The committee's methodological approach included both a new analysis of doubly labeled water (DLW) data and a review of evidence on energy expenditure. For the latter, the committee considered relevance of the assessment methodology used and its applicability to the general U.S. and Canadian populations, including age, sex, body size, body composition, physiological state (e.g., pregnancy and lactation), and level of physical activity consistent with normal health. Because common physiological states such as underweight, overweight/obesity, and prediabetes/diabetes are known to influence energy requirements, the committee sought evidence for relationships between energy balance/imbalance states and health outcomes related to the risk of chronic disease.

APPROACH FOR GATHERING DOUBLY LABELED WATER DATA

The committee was tasked to use data from studies that measure energy expenditure using DLW, which is considered the benchmark standard, to use in updating the Estimated Energy Requirement (EER) equations. Specifically, the committee was directed to use the International Atomic Energy Agency (IAEA) DLW database to derive the total energy expenditure (TEE) equations, which are the basis for deriving the EER equations. The committee augmented this database with data from other DLW studies of diverse populations known to be missing in the IAEA database. These additional data sources included the prior DRI report for energy (IOM, 2002/2005); the Study of Latinos: Nutrition and Physical Activity Assessment (SOLNAS) from the National Heart, Lung and Blood Institute (NHLBI) Biologic Specimen and Data Repository; and a source of data on pregnant and lactating women from the Children's Nutrition Research Center at the Baylor College of Medicine (CNRC).

The Indiana University School of Public Health-Bloomington was contracted to perform statistical analysis to analyze the DLW data and generate prediction equations for TEE by age/sex and life-stage groups. This analysis was then used by the committee to derive its equations for energy expenditure by population age/sex and life-stage group. A report of this statistical analysis is in Appendix G, and the committee's application of the analysis to derive EER equations is in Chapter 5.

APPROACH AND PROCESS FOR GATHERING RELEVANT LITERATURE

To identify the systematic reviews to include in its umbrella review, the committee developed a list of key topics and questions (Table 3-1) relevant to its statement of task and determined which topics required searches for existing systematic reviews. The committee then defined search terms (Appendix D) and eligibility criteria (Appendix E) for the studies included in the existing systematic reviews, and conducted literature searches in PubMed, Web of Science, and Embase between February and June 2022.

Generally, existing systematic reviews were eligible if they were published since 2000 (in English), evaluated studies of humans, and included studies that were comparative (comparing different interventions or exposures) or provided multivariable regressions of exposures of interest. Excluded were reviews of populations or samples that are not representative of generally healthy individuals in the United States or

Canada, including studies of people with specific health conditions (other than diabetes or weight category) or atypical metabolic states (e.g., athletes), as well as reviews of studies conducted in low-income or lower-middle-income countries. Additional systematic reviews and primary studies identified from other sources (e.g., reference lists, studies known to committee members, studies found in searches for other key questions) were also reviewed for possible inclusion. Eligibility criteria for these searches are listed in Appendix E.

For some key questions, no relevant systematic reviews were found. In these cases, additional informal literature searches of the primary peer-reviewed literature were conducted.

For each literature review, all search results were uploaded to a systematic review management program (Covidence) for screening. Two independent reviewers screened each article title and abstract. At least one of the reviewers was a committee member; the other reviewer was another committee member or a trained staff member. Any conflicting results were discussed by the reviewers and resolved by consensus. The full texts of included articles were reviewed by a single reviewer to determine eligibility for data extraction based on the predefined eligibility criteria. The questions used in the search were formulated by the committee and defined relevant to the task. Table 3-1 provides the results for each question reviewed.

All relevant data were extracted from each eligible systematic review into a customized spreadsheet. The extracted data included general information about the article, demographic characteristics (e.g., sample population age, sex, number of participants, life stage, race, and ethnicity), the number of studies, the specific intervention examined, the outcome, quantitative and narrative summaries of results, and information on the risk of bias of the included studies.

During the data extraction process, the methodological quality of each systematic review was evaluated using the Assessment of Multiple Systematic Reviews 2 (AMSTAR 2)[1] quality assessment tool, with minor adaptations for clarity (see Appendix F). The AMSTAR 2 questions were answered for each article by the committee member reviewing the key question. The answers were reviewed by a committee member with expertise in systematic reviews, who provided primary input on questions related to literature search strategy, risk-of-bias assessment, and meta-analytic method. This committee member also assigned an overall assessment of the quality of each review (as described in Appendix F). Revisions and overall assessments were then reviewed by the original data extractor and disagreements were discussed and settled by consensus.

[1] https://amstar.ca/Amstar-2.php (accessed November 11, 2022).

TABLE 3-1 Evidence Map: Literature Search and Screening Results

Key question
What is the association of macronutrient composition on metabolic efficiency (energy usage/expenditure)?
What is the association of body composition on metabolic efficiency (energy usage/expenditure)?
What is the effect/association of weight cycling on metabolic efficiency (energy usage/expenditure)?
What is the calorie intake needed to achieve weight loss (if overweight), weight maintenance (all), or weight gain (if underweight)?
What is the effect of body mass index (BMI; and other measures of adiposity) on energy balance or energy expenditure?
How do physical activity and energy expenditure change across the life span?
What is the relationship between different measurements of physical activity and energy expenditure?
What is the association between BMI and chronic disease, including all-cause mortality?
What is the degree of systematic bias of energy intake as assessed by self-report compared to doubly labeled water studies?
What is the association between weight change and chronic disease outcomes?
What is the effect of race or ethnicity on energy expenditure?
What is the effect of growth during childhood and adolescence on energy requirements?
What is the effect of pregnancy on energy requirements?
What is the effect of lactation on energy requirements?
What equations are available for computing basal energy expenditure?

[a] During the data extraction stage, 2 articles (systematic reviews) were moved into this review from other reviews and 7 additional articles were identified by the committee from the primary literature.

[b] During the title/abstract screening stage, 2 articles were moved into this review from other reviews.

[c] For this search, 317 articles were identified in the database searches. After removing 19 duplicates, 298 articles remained. An additional 23 articles were identified by the committee during title/abstract screening, resulting in a total of 321 articles for screening.

[d] Five additional articles were identified by the committee during data extraction.

[e] Three additional articles were identified by the committee during the full text screening stage.

[f] One article was moved into this review from another review during the data extraction stage.

[g] Two additional articles were identified by the committee during the full-text screening stage.

Records identified in database searches	Titles and abstracts screened	Full-text articles screened	Articles included for data extraction	Articles included in final set
26	26	8	6	3
60	60	8	5	1
28	22	9	13[a]	9
80	82[b]	17	6	2
317	321[c]	90	9	8
771	485	49	5	3
201	174	47	11	9
2,563	2,102	207	45[d]	36
38	32	8	8	7
1,635	1,328	47	14	13
465	465	109[e]	81	79
477	344	24	22	3
86	73	15	7	6
71	46	7	8[f]	6
50	41	7[g]	7	7

Following extraction, data synthesis was conducted separately for each of the key questions. The committee did not conduct *de novo* meta-analyses or other reanalyses of data. Reported risk of bias analyses and GRADE (or equivalent) certainty of evidence conclusions were considered from the existing systematic reviews. To document its search results, the committee developed summary tables of the studies identified based on relevant indicators used to assess DRI values (Appendix J). These included study design, setting, participant age, biological sex, life-stage group, physiological state, intervention or exposure, methods used to determine nutrient intake levels and outcome measures, sample size, attrition, and a description of the statistical analysis. Finally, the committee identified research gaps in the process of deriving DRIs for energy and in evaluating the public health implications (Chapter 9).

REFERENCES

IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press.

4

Factors Affecting Energy Expenditure and Requirements

Total energy expenditure (TEE) is the energy expended during oxidation of energy-yielding macronutrients within a 24-hour period. TEE includes three core components: resting metabolic rate, or resting energy expenditure (REE); the thermic effect of food (TEF), also referred to as diet-induced thermogenesis (DIT); and physical activity. REE, generally the largest contribution to TEE, represents the energy needed to support maintenance of normal body functioning and homeostasis. TEF is the increase in energy expenditure associated with the ingestion of food. Physical activity level (PAL) is the energy expenditure above and beyond the basal state and TEF. These three components and their determinants are shown in Figure 4-1. Table 4-1 further describes these and other terms used to indicate various components of energy expenditure. In this report, some terms are used interchangeably because the committee used the original terminology used in each reviewed paper. Additionally, while alternate terms are identified, not all are used in this report.

Part of the committee's task was to review the components of energy expenditure. It was not able to identify relevant, high-quality evidence for every component and therefore focused its discussion on topics for which it found sufficient relevant evidence. The committee's review of the evidence from systematic reviews related to TEE in general and for specific life-stage conditions such as pregnancy and lactation are discussed at the end of this chapter.

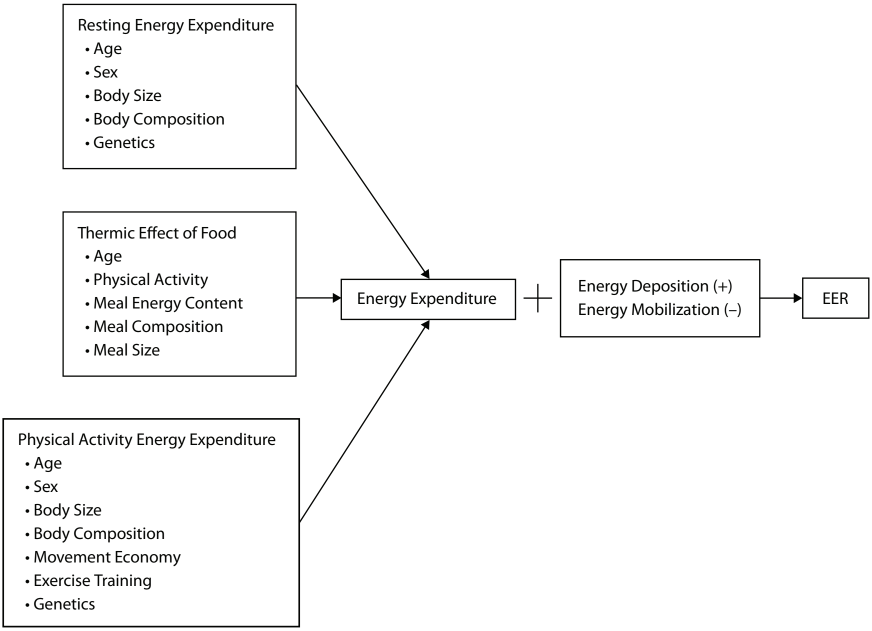

FIGURE 4-1 Components of energy expenditure and their determinants.
NOTE: EER = estimated energy requirement.
SOURCE: Adapted from Lam and Ravussin, 2016.

TABLE 4-1 Definitions for the Components of Total Energy Expenditure and Estimated Energy Requirements

Component	Alternate Terminology	Definition
Basal metabolic rate (BMR)	Basal energy expenditure (BEE)	The energy required when the human body is at complete physical, mental, and digestive rest. It is the energy required to maintain the structure and function of cells and, therefore, the minimum amount of energy expenditure compatible with life. It is usually measured after the sleeping state prior to arising from bed with the condition of being 12 or more hours postprandial/postabsorptive.
Resting metabolic rate (RMR)	Resting energy expenditure (REE)	The energy required for oxygen uptake when the body is in an awake, resting, post-absorptive, thermoneutral state. It is typically measured laying supine with the condition that there has been no exercise or food/beverage consumption in the prior 4–5 hours. It is the largest component of total energy expenditure, about 10% higher than BMR, and accounts for ~60–70% of total daily energy expenditure.

TABLE 4-1 Continued

Component	Alternate Terminology	Definition
Thermic effect of food (TEF)	Diet-induced thermogenesis (DIT)	The increase in metabolic rate after the ingestion of a meal (solid or liquid). It involves the energy expended digesting, absorbing, metabolizing, and storing energy and nutrients. It typically accounts for ~10% of total daily energy expenditure.
Physical activity energy expenditure (PAEE)		Physical activity energy expenditure is the most variable component of total daily energy expenditure and involves body movement including exercise and nonexercise activity thermogenesis (NEAT). NEAT is a result of spontaneous activity and represents the energy expended for minor movements like fidgeting and general ambulatory activity. PAEE can be calculated as the difference between total energy expenditure and basal metabolic rate plus diet induced thermogenesis (TEE – [RMR + TEF]).
Total energy expenditure (TEE)		The total daily energy expenditure comprising resting metabolic rate, thermic effect of food, and physical activity energy expenditure. For efficiency, TEE is most often presented in the literature as: (RMR + TEF + PAEE).
Physical activity level (PAL)		An indicator of the level of daily physical activity determined by the ratio of total energy expenditure to basal metabolic rate (TEE/BMR).
Energy deposition		The energy content of newly synthesized tissues estimated from the energy costs of protein and fat deposition during growth.
Energy metabolism		The use of energy from body fat and protein stores to meet energy needs, which may be accelerated in growth, injury, or stress states.

SOURCES: Butte and Caballero, 2014; Levine, 2002; Poehlman, 1989; Schutz and Jequier, 1998; Westerterp, 2004; Wong et al., 1996.

COMPONENTS OF ENERGY EXPENDITURE

Resting Energy Expenditure

Resting energy expenditure (REE) typically accounts for 60 to 70 percent of total energy expenditure (Lam and Ravussin, 2016; Poehlman, 1989). REE varies both within and between individuals and fluctuates over the course of the human life span. As shown in Figure 4-1, REE is affected by several factors, including age, sex, body size and composition, and genetics (which may include the influence of race/ethnicity). The most commonly used method to measure REE is indirect calorimetry using metabolic carts that calculate the minute-by-minute exchange of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) when an individual is at rest in the fasted state (Compher et al., 2006; Lam and Ravussin, 2016). The values of VO_2 and VCO_2 are then entered into an equation to calculate 24-hour resting metabolic rate (REE).

Commonly used equations to derive the REE include the Weir equation (Brouwer, 1957; Consolazio et al., 1963) and several empirical predictive equations that have been generated to estimate measured REE, particularly in clinical practice. These include the Harris-Benedict equation (developed in 1919), the Owen equation, the Mifflin St-Jeor equation, and the World Health Organization/Food and Agriculture Organization/United Nations University equation. The ability of estimation equations to predict accurately varies, as error rate is influenced by age, sex, ethnicity, and body mass index (BMI) category (Frankenfield et al., 2005). Accuracy in determining REE is highly important, considering its effect on weight status (Marra et al., 2017).

REVIEW OF EVIDENCE ON THE DETERMINANTS OF REE

Age/Sex Group

A recent analysis of Basal Energy Expenditure (BEE) measured by indirect calorimetry in a large sample of males and females over the life course (n = 2,008) from multiple countries (n = 29) found that BEE increased with the amount of fat-free mass (FFM) in a power law manner, after adjusting for body size, age, and sex (Pontzer et al., 2021). Specifically, size-adjusted BEE was found to increase rapidly in infants up to 15 months of age, with BEE values approximately 50 percent higher than adult values. Size-adjusted BEE then declined slowly until around 20 years of age and remained stable from 20 to 60 years before declining in older adults (Pontzer et al., 2021). The decline in BEE for older adults appears to be related to decreases in fat-free mass, and age-related reduction in organ metabolism.

A systematic review by Schwartz and Doucet (2010) of 90 studies that included 2,996 participants did not find a significant difference in sex for the reduction in REE that occurs with reducing body mass through intentional weight loss. Although there is high interindividual variability in REE, when body mass and composition are controlled in the analysis, it appears that sex has little impact on REE.

Body Size

Body size, a function of weight and height, varies among individuals from all races and ethnicities. Systematic reviews of studies that have determined REE from indirect calorimetry show a linear relationship between increasing BMI and REE. In a systematic review comparing constitutionally thin individuals (BMI ≤ 17.5) with no existing medical conditions (including eating disorders) compared to normal weight individuals, constitutionally thin individuals were found to have a lower REE compared to those of normal weight (Bailly et al., 2021). RMR results in 64 percent of the studies showed a lower RMR in constitutionally thin versus normal BMI control subjects, while 36 percent of studies showed no difference.

Whether a linear relationship between body mass and REE holds true in obesity, particularly class III obesity, is a topic of debate and is frequently challenged by studies using dynamic mathematical modeling (Heymsfield et al., 2019). A systematic review of 20 studies by Kee et al. (2012) showed that REE ranged from 1,800 to 2,600 kcal/d among individuals with morbid obesity, and that REE increased with increasing body mass. While body composition was not reported in all studies in the systematic review, Das et al. (2003) demonstrated that fat mass (FM) contributes significantly to REE variability in individuals with BMI ≥ 50, both before and after weight loss.

A number of systematic reviews examining weight loss show an effect of either adaptive thermogenesis or energy compensation such that REE is reduced more than predicted. These studies found that the reduction in REE varied widely, from 12 to 44 percent less than predicted, which equates to about 220 kcal less per day (Dhurandar et al., 2015; Nunes et al., 2022a,b; Schwartz et al., 2012). One systematic review of seven studies with 361 participants showed that a gradual reduction in body mass (about 0.5 kg/week) resulted in less reduction in REE compared to rapid weight change (about 1.1 kg/week) (Ashtary-Larky et al., 2020).

Body Composition

Assessing body composition is a foundational element of energy metabolism research. The human body contains tissues and organs of varying metabolic activity, with the simplest division of total body mass into two compartments: fat mass (FM) also known as stored fat found in adipose tissue, and fat-free mass (FFM), which includes smooth and skeletal muscle, connective tissue, water, and bone. Although adipose tissue is the main storage site for energy, in the form of triglycerides, it has a low metabolic rate at about 5 kcal/kg compared to 20 kcal/kg for FFM (Javed et al., 2010; Wang et al., 2010). In the systematic review by Bailly et al. (2021), the authors reported that despite very low FFM in constitutionally thin individuals, these individuals have increased metabolic activity when normalized to FFM compared to normal weight individuals, suggesting a highly metabolically active FFM.

Given that FFM is a strong predictor of REE, accounting for 60 to 80 percent of interindividual variance in REE, measurement of REE is often adjusted for FFM by sex as a means of adjusting REE for differences in body size, since body weight alone can explain only about 50 percent of the variance in REE (Gallagher et al., 1996).

More recent investigations consider differences in organ energy expenditure as a component of FFM, which may account for interindividual variability in REE associated with age, sex, and race/ethnicity. Older individuals appear to have a lower REE, however, even after controlling for organ and tissue mass. Thus, age-related changes in body composition, including loss of body water, bone mineral content, FFM, and an increase in the distribution of FM, influence REE.

Periods of underfeeding are typically accompanied by compensatory metabolic responses and losses of FFM during episodes of energy deficit, which generally result in reduced energy expenditure. Taken together, metabolic responses to decreased energy intake and weight loss are part of a complex and dynamic energy balance system in which changes to individual components can lead to interrelated compensatory responses (Casanova et al., 2019).

Genetic Traits: Race and Ethnicity

Self-reported race is the only legal basis for racial categorization (Cooper, 1994), and nutrition research almost exclusively uses self-reported race and ethnicity to describe participants and population groups engaged in research. In the public health context, planners use conventional racial or ethnic population characteristics as a proxy for planning programs, facilitating program accessibility, and targeting public health messages. The understanding and use of the concepts of race and ethnicity have evolved over the years.

Currently, the social and political construct that is race/ethnicity is thought to reflect differential distribution of resources, including the availability of high-quality foods, housing, education, transportation, and access to health care, leading to significant inequities among certain population groups (Cooper, 2013; White et al., 2020). These upstream factors influencing health equity are commonly referred to as social determinants of health (WHO, 2022).

In this case, race and ethnicity are not modifiable factors but rather act as proxies for other determinants that can be changed to improve health.

About 10 percent of the U.S. population identified as multiracial in the 2020 census, up almost 300 percent from 2010 (Jones et al., 2021). In addition, more than 15 percent identified as "some other race either alone or in combination," a description that is exclusive of the five categories listed in the census survey: White, Black/African American, American Indian/Alaskan Native, Asian, or Native Hawaiian/Other Pacific Islander. The evidence quantifying the effect of race and/or ethnicity on energy expenditure remains inconclusive despite a relatively robust examination in the scientific literature. The vast majority of studies over the past 20 years have focused on the comparison of REE between Black and White individuals, most with an aim of elucidating documented differences in overweight and obesity between these racial groups.

A preponderance of studies, as shown in Appendix J, Table J-5, reported a significantly lower REE among Black compared to White adults, even after adjustment for body composition, meaning FFM and FM (Adzika Nsatimba et al., 2016; Most et al., 2018; Olivier et al., 2016; Reneau et al., 2019; Spaeth et al., 2015). The same pattern was observed among studies of prepubescent children and adolescents (Bandini et al., 2002; McDuffie et al., 2004; Pretorius et al., 2021; Sun et al., 2001; Tershakovec et al., 2002). Of the 19 studies reporting lower adjusted REE for Black adults, the range of mean differences was 50 to 250 kcal/d with the median of mean differences about 120 kcal/d; for children, the range of mean differences was 36 to 120 kcal/d and the median was 77 kcal/d. The observed differences in REE tended to be attenuated, however, for studies in which REE was adjusted for truncal lean mass, meaning highly metabolically active organ mass, and/or appendicular lean body mass (the sum of the lean muscle mass of the upper and lower extremities adjusted for height) (Byrne et al., 2003; Gallagher et al., 1997, 2006; Hunter et al., 2000; Javed et al., 2010; Jones et al., 2004).

Few studies have examined the effect of race/ethnicity on TEE in either adults or children. In studies among adults, seven reported a significantly lower TEE in Blacks (median of mean differences about 138 kcal/d) (Blanc et al., 2004; DeLany et al., 2014; Dugas et al., 2009; Lam et al., 2014; Most et al., 2018; Walsh et al., 2004; Weinsier et al., 2000), and four reported no statistical differences after adjustment for body composition (Hunter et al., 2000; Katzmaryk et al., 2018; Kushner et al., 1995; Lovejoy et al., 2001). Studies of children reported similar results; two studies reported lower TEE among Blacks (mean difference of 86 kcal/day) (Bandini et al., 2002; DeLany et al., 2002), and two reported no statistically significant difference (Goran et al., 1998; Sun et al., 1998). Attempts to understand the mechanisms responsible for the lower observed REE (and to a lesser extent, TEE) among Blacks compared to Whites in the United States suggest regional body composition differences, i.e., high metabolically active truncal organ mass or low metabolically active appendicular skeletal muscle mass, as one potential explanation for the lack of significant differences (Gallagher et al., 1997).

The relatively few studies that have compared REE or TEE in race/ethnic groups other than Blacks and Whites generally reported no statistically significant differences between groups. Groups examined include adult Hispanics (Deemer et al., 2010), Pima Indians (Christin et al., 1993; Fontveille et al., 1994; Saad et al., 1991), Maori and Pacific Islanders (Rush et al., 1997), Asians (Song et al., 2016; Wouters-Adriaens and Westerterp, 2008), and South Asian Indians (Soares et al., 1998; Song et al., 2016). A few studies also examined energy expenditure among children: Pima Indians (Fontveille et al., 1992), Hispanics (Dugas et al., 2008), Mohawks (Goran et al., 1995, 1998), and Maori and Pacific Islanders (Rush et al., 2003). See Appendix J, Table J-5 for additional details.

Attempts to understand the mechanisms responsible for the lower observed REE (and to a lesser extent, TEE) among Blacks compared to Whites in the United States point to regional body composition differences—meaning highly metabolically active truncal organ mass or low metabolically active appendicular skeletal muscle mass—as one potential explanation (Gallagher et al., 1997). Differences in mitochondrial function (Toledo et al., 2018) and mitochondrial DNA haplotypes (Tranah et al., 2011) may also contribute to differences in energy expenditure between population groups.

Using ancestry informative markers among the participants of a substudy of the U.S.-based Health, Aging and Body Composition Study, investigators reported a significant association between proportion of European genetic admixture among Black participants and REE adjusted for body composition (Manini et al., 2011). Each percent of European admixture was associated with a 1.6 kcal/day higher adjusted REE in these older adults. If confirmed in additional studies, this finding may help explain the variability across studies reporting differences in energy expenditure between Black and White individuals. For context, multiple studies have reported wide variability in the degree of West African and European admixture among self-identified Blacks or African Americans in the United States. The mean European admixture among self-identified Blacks in any given study ranges from about 15 to 25 percent (Klimentidis et al., 2016; Parra et al., 1998; Worsham et al., 2011); however, the range of European admixture can be as wide as 0 to 70 percent (Al-Alem et al., 2014; Manini et al., 2011).

Thermic Effect of Food

Factors that influence TEF include age, physical activity, and a meal's energy content, composition (i.e., quantity and type of carbohydrate, protein, and fat content of a meal), and size (Calcagno et al., 2019). The TEF, which has been shown to comprise approximately 10 percent of daily energy expenditure, includes obligatory thermogenesis. Obligatory thermogenesis is accounted for by the energy cost of absorption and transport of nutrients, and synthesis of carbohydrate, protein, and fat in tissues (Saito et al., 2020).

Review of Evidence on the Determinants of TEF

Physical Activity

A review by Calcagno and colleagues (2019) identified one study that examined the effect of physical activity on TEF. The study showed that in both younger and older men, those who were active had an approximately 45 percent higher TEF than those who were inactive. Further evidence from a study of active females suggests that consumption of a meal in combination with a short period of moderate to vigorous physical activity (MVPA) results in a greater total energy expenditure than similar activity performed in a fasted state (Binns et al., 2015).

Meal Energy Content, Composition, and Size

The main determinant of TEF is energy and macronutrient composition of the meal, of which proteins have the highest thermogenic response. DIT values are approximately 0 to 3 percent for fat, 5 to 10 percent for carbohydrate, 20 to 30 percent for protein, and 10 to 30 percent for alcohol (Westerterp, 2004).

A systematic review that examined differences in the effects on DIT of meals consumed after fasting conducted mixed model meta-regression analyses that included only energy intake and DIT. It showed that for every 24 kcal increase in energy intake, DIT increased by 0.26 kcal/day (Quatela et al., 2016).

In a systematic review that included 15 studies, 9 showed a significant effect of the type of fatty acids on DIT. Three studies described a DIT increment with the use of polyunsaturated fatty acid, two reported a greater DIT as a result of the use of medium chain fatty acids, and four reported differences with the use of specific foods or oils. Specifically, postprandial fat oxidation and postprandial energy expenditure were greater with the use of alpha linolenic acid–enriched diacylglycerol compared to triacylglycerol. However, no conclusion could be drawn when only the fatty acid composition of the diet was evaluated for DIT (Cisneros et al., 2019).

Park et al., examined dietary factors affecting DIT in studies that included individuals with obesity. In this systematic review of studies published from 2009 to 2019, only two studies of very small sample sizes showed no differences in DIT between obese and lean individuals with varying carbohydrate and protein composition of isocaloric meals (Park et al., 2020). This finding is in contrast to an older review by de Jonge and Bray (1997), which reported that in 29 studies of age-matched individuals, 22 reported a reduction in DIT for individuals with obesity compared to lean individuals. Thus, the issue of the obese state due to insulin resistance being associated with lower DIT remains undecided. The variability in how DIT is measured and the complex interaction of human behaviors including physical activity makes it difficult to estimate DIT accurately and compare results across studies.

Physical Activity Level

Physical activity is the most variable energy component. Energy expenditure from activity is the energy required for the body to move (i.e., perform muscular work) during non-exercise activity thermogeneis (e.g., fidgeting, maintaining posture, and activities of daily living) and voluntary (e.g., exercise, sports) activity. It varies greatly as a proportion of TEE and has been shown to range from a low of 15 percent for sedentary individuals up to 50 percent of TEE for physically active individuals (Livingstone et al., 1991; Ravussin et al., 1986).

Determinants of PAEE include age, sex, body size and composition, movement economy, exercise training, and genetic traits, all of which interact and can result in energy adaptations. Resources such as the Compendium of Physical Activities can provide estimates of an individual's energy expenditure for specific activities (Ainsworth et al., 2011; Butte et al., 2018).

Review of Evidence on the Determinants of PAL

Age/Sex

PAL varies across the life span. Researchers can obtain precise measures of intraindividual or interindividual differences in PAL using doubly labeled water (DLW), indirect calorimetry, and room calorimetry. Because DLW is used only for measuring free-living TEE and may be cost-prohibitive, researchers often use estimates of physical activity from questionnaires or device-based measures. Questionnaires tend to have a high degree of error because they rely on individual recall and quantification of activity level (see Chapter 6 for further discussion of methodologies). Device-based measures (e.g., ActiGraph; GeneActive, Apple Watch, and Fitbit) use sensors such as accelerometers to capture an individual's movement and are considered to provide a better estimate of typical activity patterns than questionnaires, but they lack details about the type of activity performed. Furthermore, a lack of consensus on intensity criteria along with variation in device wear location make it challenging to quantify time in intensity categories and comparing estimates across studies (Watson et al., 2014).

Craigie et al. (2011) conducted a systematic review of literature on tracking physical activity and dietary intake from childhood to adulthood. Three studies in this review, which included over 2,000 participants, found that tracking of physical activity from adolescence into adulthood was stronger among males than females. Between 44 and 59 percent of males maintained physical activity during the 5- to 8-year follow-up.

Tanaka et al. (2014) examined longitudinal changes in overall sedentary behavior and how those changes were associated with adiposity in children and adolescents. This systematic review included 7,238 children and adolescents and found that during a 1- to 10-year follow-up among 3- to 13-year-olds, sedentary behavior increased with age, by approximately 30 minutes of additional daily sedentary behavior per year. Little evidence was available to demonstrate any influence of changes in sedentary behavior on changes in adiposity.

Body Size and Composition

A systematic review by Carneiro et al. (2016) examined differences in activity-based energy expenditure in individuals with and without obesity. All four studies included in the analysis reported that individuals with obesity had higher absolute activity energy expenditure than those without obesity. After adjustment for FFM or body weight, two studies showed no difference between the two population groups. The conclusion of the review was that activity energy expenditure was not different in individuals with obesity; rather, they have altered activity patterns and greater amounts of sedentary time, resulting in overall lower activity energy expenditure values. However, higher REE in those with obesity that was reported in most studies could be caused by not adjusting for body composition.

Carneiro et al. (2016) also examined differences in daily energy expenditure between those with and those without obesity. In the three studies included in the systematic review, absolute daily energy expenditure was higher in the group with obesity (approximately 2,690 kcal/d) than in those without obesity (approximately 2,380 kcal/d). Similar to the findings on activity energy expenditure, the difference between the two groups disappeared after adjusting for FFM and body weight.

Movement Economy and Exercise Training

Movement economy is the oxygen cost to perform a given submaximal task. The more trained an individual is, the better their economy (i.e., the oxygen cost or energy expenditure will be lower) (Barnes and Kilding, 2015). This principle also relates to motor coordination, which is a measure of the ability to coordinate muscle activation in multiple body parts to perform a given task. Motor coordination is still developing in children and youth, thus their movement economy is typically poorer (i.e., the energy cost of an activity such as walking is higher) than an adult's. Children's motor coordination improves along with movement economy as skill development proceeds. In adults, training improves movement economy.

OTHER CONSIDERATIONS

Carbohydrate Restriction

There has been great interest in understanding the effect of a restricted carbohydrate diet on TEE to explain the heterogeneity found in weight loss clinical trials. The rationale for examining this relationship is the hypothesis that with moderate restriction of carbohydrate over a longer period of time, a shift in the metabolic pathway can occur from carbohydrate oxidation to fat oxidation without bringing on a ketosis condition, thereby subsequently reducing TEE through several mechanisms including a reduction in voluntary physical activity energy expenditure. Ludwig et al. (2021) conducted an updated systematic review with a meta-analysis of previous work by Hall and Guo (2017) and added trials conducted since 2016 up through March 2020. Carbohydrate restriction was allowed to vary in the trials, but study duration was dichotomized at greater than or less than 2 weeks. In studies with short-term carbohydrate restriction (<2.5 weeks), the systematic review found that a lower carbohydrate diet did result in reduced TEE. However, when a restricted carbohydrate diet was maintained for more than 2.5 weeks, TEE increased by approximately 50 kcal/day for every 10 percent decrease in carbohydrate as a percentage of energy intake. The stratification by study duration accounted for the most variability in TEE (R^2 = 57.2 percent). The method used to measure TEE, whether whole-room calorimetry or DLW, did not significantly add to the heterogeneity. A conclusion of this work is that shorter versus longer duration of carbohydrate restriction studies are not examining the same physiological states, which may explain the pattern of weight loss seen in clinical trials and thus, not indicative of the success of these short-term trials to treat obesity.

Pregnancy and Lactation

Many metabolic and physiological changes that influence energy requirements occur during the life stages of pregnancy and lactation. Previous derivations of requirements for pregnancy were based on theoretical energy costs associated with the products of conception (e.g., the fetus, placenta, maternal breast and uterine tissue, and maternal fat). For lactation, requirements have been based on the energy costs associated with producing a specific volume of breast milk for the infant, accounting for the mobilization of maternal fat stores from pregnancy to provide additional energy resources during the postpartum period. Butte and King (2005) comprehensively examined these energy costs and how their estimates have changed over time.

Previous estimates of the energy costs of pregnancy (which considered FM and FFM accretion associated with the products of conception) may have led to overestimation of energy requirements during this life stage. A recent systematic review and meta-analysis provides evidence of wide variability in TEE and in REE and other energy expenditure components during pregnancy (Savard et al., 2021). The data support the notion that REE and TEE increase over the course of pregnancy, with greater increases observed when baseline measurement included a preconception time point. Median increases in TEE were 6.2 percent (144 kcal), 7.1 percent (170 kcal), and 12.0 percent (290 kcal) between early and mid-, mid- and late, and early and late pregnancy, respectively. Most of the included studies enrolled normal weight, Caucasian women, however, and had small sample sizes. The two studies that stratified results by prepregnancy BMI showed smaller increases in TEE for women with overweight and obesity. Most studies did not stratify by adequacy of gestational weight gain. Therefore, the constant physiological adaptation during pregnancy (such as gradual reductions in physical activity expenditure and in DIT) imply that the energy cost of pregnancy should be lower than the costs published by the Institute of Medicine (IOM, 2002/2005).

For lactation, a systematic review that examined volumes and the energy content of breast milk showed a weighted mean milk transfer of 779 g/day at 3 to 4 months, 826 g/day at 5 to 6 months, and 894 g/day at 6 months. Among nine studies, no marked increase in milk transfers were reported during the 2- to 5-month period. The weighted mean metabolizable energy content of milk from 25 studies of 777 mother–infant dyads was 2.6 kJ/g (equivalent to 0.62 kcal/g) (Reilly et al., 2005).

Four individual studies on the energy costs of lactation have been conducted since the systematic review mentioned above (see Appendix J for details). Thakkar et al. (2013) measured the energy content of human milk at 65.92 kcal/100 ml starting at 1 month of age and 70.24 kcal/100 ml at 3 months of age. The energy content of human milk produced for male infants was 24 percent higher at 3 months of age than that produced for females. Two additional studies of the same group of mother–infant dyads used DLW to estimate mean milk intake at 923 g/day at 15 weeks and 999 g/day at 25 weeks among exclusively breastfed infants (Nielsen et al., 2011, 2013). Milk energy content was the same for males and females, 2.72 kJ/g at 15 weeks and 2.62 kJ/g at 25 weeks. Significant differences in total energy intakes by sex were observed at 25 weeks: males consumed 2,582 kJ/d and females 2,403 kJ/d at 15 weeks, and males consumed 2,748 kJ/d and females 2,449 kJ/d at 25 weeks.

Pereira et al. (2019) used whole-body calorimetry to measure REE at 3 and 9 months and TEE at 9 months in a sample of approximately 50 mother–infant dyads. Average breast milk volume was 771 g/d at 3 months, equating to a breast milk energy output of 678 kcal/d. Average breast milk volume was 530 g/day at 9 months (in the presence of complementary feeding), equating to 465 kcal/day. REE increased by 3.2 percent from 3 to 9 months. No difference in TEE was observed between lactating and nonlactating women at 9 months.

FINDINGS AND CONCLUSIONS

Determinants of Resting Energy Expenditure

Findings

The committee's review of the current evidence confirms that REE is the largest contributor to TEE, varies both within and between individuals, and fluctuates over the course of the human life span. The committee found evidence for a linear relationship between increasing body size and REE. The evidence shows that REE adjusted for body size increases rapidly in infants up to 15 months of age and then begins to decline slowly up to age 20, when REE becomes stable to about age 60 years. Evidence reviewed confirmed that the potential impact of sex on REE is related to differences in body mass and composition. The committee found systematic review evidence was lacking on the influence of Class III or morbid obesity on REE. Also lacking was systematic review evidence on the influence of the gut microbiome and organ tissue energy expenditure to explain the variability in REE among individuals.

The committee finds that data stratified by prepregnancy BMI are lacking, especially for women with overweight and obesity. Further, most of the studies examined did not stratify by adequacy of gestational weight gain. Among lactating women, evidence reviewed by the committee showed that REE increased by 3.2 percent from 3 to 9 months postpartum, although no significant differences were observed in TEE between lactating and nonlactating women at 9 months.

The committee finds that the current evidence confirms that physical activity is the most variable energy component, ranging from 15 to 50 percent of TEE. Additionally, physical activity decreases with age and is influenced by previous activity levels. Activity energy expenditure and total daily energy expenditure were shown to differ between individuals with and without obesity in terms of absolute levels, but differences disappeared after adjusting for FFM and body weight. Systematic review evidence on the influence of movement economy and motor coordination, particularly in persons with obesity, remains lacking.

Conclusions

The committee concludes that overall, the evidence to support an interaction between BMI and REE is limited, especially to examine the influence of BMI on REE by age/sex or life stage. Further, the total energy requirements for pregnancy have not been aligned with current recommendations for rates of weight gain. The IOM (2002/2005) energy requirements may have overestimated requirements during pregnancy among women with overweight or obesity.

Race and Ethnicity

Findings

The committee finds that race and ethnicity are not modifiable factors but rather social constructs that act as proxies for other determinants. While studies reported a significant lower REE among Black compared to White adults, regional body composition differences, and differences in mitochondrial function and mitochondrial DNA haplotypes provide potential explanations for these data. Furthermore, using ancestry informative markers may help explain the variability across studies reporting differences in energy expenditure between Black and White individuals.

Conclusions

The committee concludes that a better understanding of whether race/ethnicity reliably and consistently affects energy expenditure or is a social and political construct that serves as a proxy for other determinants affecting *energy expenditure such as cultural, environmental, physical activity, and/or behavioral differences, is crucial to both research and public health efforts.*

REFERENCES

Adzika Nsatimba, P. A., K. Pathak, and M. J. Soares. 2016. Ethnic differences in resting metabolic rate, respiratory quotient and body temperature: A comparison of Africans and European Australians. *European Journal of Nutrition* 55(5):1831-1838.

Ainsworth, B. E., W. L. Haskell, S. D. Herrmann, N. Meckes, D. R. Bassett, Jr., C. Tudor-Locke, J. L. Greer, J. Vezina, M. C. Whitt-Glover, and A. S. Leon. 2011. 2011 compendium of physical activities: A second update of codes and met values. *Medicine and Science in Sports and Exercise* 43(8):1575-1581.

Al-Alem, U., G. Rauscher, E. Shah, K. Batai, A. Mahmoud, E. Beisner, A. Silva, C. Peterson, and R. Kittles. 2014. Association of genetic ancestry with breast cancer in ethnically diverse women from Chicago. *PloS One* 9(11):e112916.

Ashtary-Larky, D., R. Bagheri, A. Abbasnezhad, G. M. Tinsley, M. Alipour, and A. Wong. 2020. Effects of gradual weight loss v. rapid weight loss on body composition and RMR: A systematic review and meta-analysis. *British Journal of Nutrition* 124(11):1121-1132.

Bailly, M., A. Boscaro, B. Pereira, L. Feasson, Y. Boirie, N. Germain, B. Galusca, D. Courteix, D. Thivel, and J. Verney. 2021. Is constitutional thinness really different from anorexia nervosa? A systematic review and meta-analysis. *Reviews in Endocrine and Metabolic Disorders* 22(4):913-971.

Bandini, L. G., A. Must, J. L. Spadano, and W. H. Dietz. 2002. Relation of body composition, parental overweight, pubertal stage, and race-ethnicity to energy expenditure among premenarcheal girls. *American Journal of Clinical Nutrition* 76(5):1040-1047.

Barnes, K. R., and A. E. Kilding. 2015. Running economy: Measurement, norms, and determining factors. *Sports Medicine Open* 1(1):8.

Binns, A., M. Gray, and R. Di Brezzo. 2015. Thermic effect of food, exercise, and total energy expenditure in active females. *Journal of Science and Medicine in Sport* 18(2):204-208.

Blanc, S., D. A. Schoeller, D. Bauer, M. E. Danielson, F. Tylavsky, E. M. Simonsick, T. B. Harris, S. B. Kritchevsky, and J. E. Everhart. 2004. Energy requirements in the eighth decade of life. *American Journal of Clinical Nutrition* 79(2):303-310.

Brouwer, E. 1957. On simple formulae for calculating the heat expenditure and the quantities of carbohydrate and fat oxidized in metabolism of men and animals, from gaseous exchange (oxygen intake and carbonic acid output) and urine-n. *Acta Physiologica et Pharmacologica Neerlandica* 6:795-802.

Butte, N. F., and B. Caballero. 2014. Energy needs: Assessment and requirements. In *Modern Nutrition in Health and Disease.* 11th ed., edited by A. C. Ross, B. Caballero, R. J. Cousins, K. L. Tucker, and T. R. Ziegler. Baltimore, MD: Lippincott, Williams and Wilkins.

Butte, N. F., and J. C. King. 2005. Energy requirements during pregnancy and lactation. *Public Health Nutrition* 8(7A):1010-1027.

Butte, N. F., K. B. Watson, K. Ridley, I. F. Zakeri, R. G. McMurray, K. A. Pfeiffer, S. E. Crouter, S. D. Herrmann, D. R. Bassett, A. Long, Z. Berhane, S. G. Trost, B. E. Ainsworth, D. Berrigan, and J. E. Fulton. 2018. A youth compendium of physical activities: Activity codes and metabolic intensities. *Medicine and Science in Sports and Exercise* 50(2):246-256.

Byrne, N. M., R. L. Weinsier, G. R. Hunter, R. Desmond, M. A. Patterson, B. E. Darnell, and P. A. Zuckerman. 2003. Influence of distribution of lean body mass on resting metabolic rate after weight loss and weight regain: Comparison of responses in white and black women. *American Journal of Clinical Nutrition* 77(6):1368-1373.

Calcagno, M., H. Kahleova, J. Alwarith, N. N. Burgess, R. A. Flores, M. L. Busta, and N. D. Barnard. 2019. The thermic effect of food: A review. *Journal of the American College of Nutrition* 38(6):547-551.

Carneiro, I. P., S. A. Elliott, M. Siervo, R. Padwal, S. Bertoli, A. Battezzati, and C. M. Prado. 2016. Is obesity associated with altered energy expenditure? *Advances in Nutrition* 7(3):476-487.

Casanova, N., K. Beaulieu, G. Finlayson, and M. Hopkins. 2019. Metabolic adaptations during negative energy balance and their potential impact on appetite and food intake. *Proceedings of the Nutrition Society* 78(3):279-289.

Christin, L., M. O'Connell, C. Bogardus, E. Danforth, Jr., and E. Ravussin. 1993. Norepinephrine turnover and energy expenditure in Pima Indian and white men. *Metabolism: Clinical and Experimental* 42(6):723-729.

Cisneros, L. C. V., A. G. M. Moreno, A. Lopez-Espinoza, and A. C. Espinoza-Gallardo. 2019. Effect of the fatty acid composition of meals on postprandial energy expenditure: A systematic review. *Revista da Associacao Medica Brasileira (1992)* 65(7):1022-1031.

Compher, C., D. Frankenfield, N. Keim, L. Roth-Yousey, and Evidence Analysis Working Group. 2006. Best practice methods to apply to measurement of resting metabolic rate in adults: A systematic review. *Journal of the American Dietetic Association* 106(6):881-903.

Consolazio, C. F., R. E. Johnson, and L. J. Pecora. 1963. *Physiological measurements of metabolic functions in man*. New York: McGraw-Hill.

Cooper, R. S. 1994. A case study in the use of race and ethnicity in public health surveillance. *Public Health Reports* 109(1):46-52.

Cooper, R. S. 2013. Race in biological and biomedical research. *Cold Spring Harbor Perspectives in Medicine* 3(11).

Craigie, A. M., A. A. Lake, S. A. Kelly, A. J. Adamson, and J. C. Mathers. 2011. Tracking of obesity-related behaviours from childhood to adulthood: A systematic review. *Maturitas* 70(3):266-284.

Das, S. K., S. B. Roberts, M. A. McCrory, L. K. Hsu, S. A. Shikora, J. J. Kehayias, G. E. Dallal, and E. Saltzman. 2003. Long-term changes in energy expenditure and body composition after massive weight loss induced by gastric bypass surgery. *American Journal of Clinical Nutrition* 78(1):22-30.

Deemer, S. E., G. A. King, S. Dorgo, C. A. Vella, J. W. Tomaka, and D. L. Thompson. 2010. Relationship of leptin, resting metabolic rate, and body composition in premenopausal Hispanic and non-Hispanic white women. *Endocrine Research* 35(3):95-105.

de Jonge, L., and G. A. Bray. 1997. The thermic effect of food and obesity: A critical review. *Obesity Research* 5(6):622-631.

DeLany, J. P., G. A. Bray, D. W. Harsha, and J. Volaufova. 2002. Energy expenditure in preadolescent African American and white boys and girls: The Baton Rouge Children's Study. *American Journal of Clinical Nutrition* 75(4):705-713.

DeLany, J. P., J. M. Jakicic, J. B. Lowery, K. C. Hames, D. E. Kelley, and B. H. Goodpaster. 2014. African American women exhibit similar adherence to intervention but lose less weight due to lower energy requirements. *International Journal of Obesity (2005)* 38(9):1147-1152.

Dhurandhar, E. J., K. A. Kaiser, J. A. Dawson, A. S. Alcorn, K. D. Keating, and D. B. Allison. 2015. Predicting adult weight change in the real world: A systematic review and meta-analysis accounting for compensatory changes in energy intake or expenditure. *International Journal of Obesity* 39(8):1181-1187.

Dugas, L. R., K. Ebersole, D. Schoeller, J. A. Yanovski, S. Barquera, J. Rivera, R. Durazo-Arzivu, and A. Luke. 2008. Very low levels of energy expenditure among pre-adolescent Mexican-American girls. *International Journal of Pediatric Obesity* 3(2):123-126.

Dugas, L. R., R. Cohen, M. T. Carstens, P. F. Schoffelen, A. Luke, R. A. Durazo-Arvizu, J. H. Goedecke, N. S. Levitt, and E. V. Lambert. 2009. Total daily energy expenditure in black and white, lean and obese South African women. *European Journal of Clinical Nutrition* 63(5):667-673.

Fontvieille, A. M., J. Dwyer, and E. Ravussin. 1992. Resting metabolic rate and body composition of Pima Indian and Caucasian children. *International Journal of Obesity and Related Metabolic Disorders* 16(8):535-542.

Fontvieille, A. M., R. Rising, M. Spraul, D. E. Larson, and E. Ravussin. 1994. Relationship between sleep stages and metabolic rate in humans. *American Journal of Physiology* 267(5 Pt 1):E732-737.

Frankenfield, D., L. Roth-Yousey, and C. Compher. 2005. Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: A systematic review. *Journal of the American Dietetic Association* 105(5):775-789.

Gallagher, D., M. Visser, Z. Wang, T. Harris, R. N. Pierson, Jr., and S. B. Heymsfield. 1996. Metabolically active component of fat-free body mass: Influences of age, adiposity, and gender. *Metabolism: Clinical and Experimental* 45(8):992-997.

Gallagher, D., M. Visser, R. E. De Meersman, D. Sepulveda, R. N. Baumgartner, R. N. Pierson, T. Harris, and S. B. Heymsfield. 1997. Appendicular skeletal muscle mass: Effects of age, gender, and ethnicity. *Journal of Applied Physiology (1985)* 83(1):229-239.

Gallagher, D., J. Albu, Q. He, S. Heshka, L. Boxt, N. Krasnow, and M. Elia. 2006. Small organs with a high metabolic rate explain lower resting energy expenditure in African American than in white adults. *American Journal of Clinical Nutrition* 83(5):1062-1067.

Goran, M. I., M. Kaskoun, R. Johnson, C. Martinez, B. Kelly, and V. Hood. 1995. Energy expenditure and body fat distribution in Mohawk children. *Pediatrics* 95(1):89-95.

Goran, M. I., T. R. Nagy, B. A. Gower, M. Mazariegos, N. Solomons, V. Hood, and R. Johnson. 1998. Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: Implications for energy requirements. *American Journal of Clinical Nutrition* 68(3):675-682.

Hall, K. D., and J. Guo. 2017. Obesity energetics: Body weight regulation and the effects of diet composition. *Gastroenterology* 152(7):1718-1727.e1713.

Heymsfield, S. B., D. M. Thomas, A. Bosy-Westphal, and M. J. Muller. 2019. The anatomy of resting energy expenditure: Body composition mechanisms. *European Journal of Clinical Nutrition* 73(2):166-171.

Hunter, G. R., R. L. Weinsier, B. E. Darnell, P. A. Zuckerman, and M. I. Goran. 2000. Racial differences in energy expenditure and aerobic fitness in premenopausal women. *American Journal of Clinical Nutrition* 71(2):500-506.

IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press.

Javed, F., Q. He, L. E. Davidson, J. C. Thornton, J. Albu, L. Boxt, N. Krasnow, M. Elia, P. Kang, S. Heshka, and D. Gallagher. 2010. Brain and high metabolic rate organ mass: Contributions to resting energy expenditure beyond fat-free mass. *American Journal of Clinical Nutrition* 91(4):907-912.

Jones, A., Jr., W. Shen, M. P. St-Onge, D. Gallagher, S. Heshka, Z. Wang, and S. B. Heymsfield. 2004. Body-composition differences between African American and white women: Relation to resting energy requirements. *American Journal of Clinical Nutrition* 79(5):780-786.

Jones, N., R. Marks, R. Ramirez, and M. Rios-Vargas. 2021. *2020 Census illuminates racial and ethnic composition of the country*. https://www.census.gov/library/stories/2021/08/improved-race-ethnicity-measures-reveal-united-states-population-much-more-multiracial.html (accessed November 23, 2022).

Katzmarzyk, P. T., J. Most, L. M. Redman, J. Rood, and E. Ravussin. 2018. Energy expenditure and substrate oxidation in white and African American young adults without obesity. *European Journal of Clinical Nutrition* 72(6):920-922.

Kee, A. L., E. Isenring, I. Hickman, and A. Vivanti. 2012. Resting energy expenditure of morbidly obese patients using indirect calorimetry: A systematic review. *Obesity Reviews* 13(9):753-765.

Klimentidis, Y. C., A. Arora, J. Zhou, R. Kittles, and D. B. Allison. 2016. The genetic contribution of West-African ancestry to protection against central obesity in African-American men but not women: Results from the ARIC and MESA studies. *Frontiers in Genetics* 7:89.

Kushner, R. F., S. B. Racette, K. Neil, and D. A. Schoeller. 1995. Measurement of physical activity among black and white obese women. *Obesity Research* 3(Suppl 2):261s-265s.

Lam, Y. Y., and E. Ravussin. 2016. Analysis of energy metabolism in humans: A review of methodologies. *Molecular Metabolism* 5(11):1057-1071.

Lam, Y. Y., L. M. Redman, S. R. Smith, G. A. Bray, F. L. Greenway, D. Johannsen, and E. Ravussin. 2014. Determinants of sedentary 24-h energy expenditure: Equations for energy prescription and adjustment in a respiratory chamber. *American Journal of Clinical Nutrition* 99(4):834-842.

Levine, J. A. 2002. Non-exercise activity thermogenesis (NEAT). *Best Practice & Research: Clinical Endocrinology & Metabolism* 16(4):679-702.

Livingstone, M. B., J. J. Strain, A. M. Prentice, W. A. Coward, G. B. Nevin, M. E. Barker, R. J. Hickey, P. G. McKenna, and R. G. Whitehead. 1991. Potential contribution of leisure activity to the energy expenditure patterns of sedentary populations. *British Journal of Nutrition* 65(2):145-155.

Lovejoy, J. C., C. M. Champagne, S. R. Smith, L. de Jonge, and H. Xie. 2001. Ethnic differences in dietary intakes, physical activity, and energy expenditure in middle-aged, premenopausal women: The Healthy Transitions Study. *American Journal of Clinical Nutrition* 74(1):90-95.

Ludwig, D. S., S. L. Dickinson, B. Henschel, C. B. Ebbeling, and D. B. Allison. 2021. Do lower-carbohydrate diets increase total energy expenditure? An updated and reanalyzed meta-analysis of 29 controlled-feeding studies. *Journal of Nutrition* 151(3):482-490.

Manini, T. M., K. V. Patel, D. C. Bauer, E. Ziv, D. A. Schoeller, D. C. Mackey, R. Li, A. B. Newman, M. Nalls, J. M. Zmuda, and T. B. Harris. 2011. European ancestry and resting metabolic rate in older African Americans. *European Journal of Clinical Nutrition* 65(6):663-667.

Marra, M., I. Cioffi, R. Sammarco, C. Montagnese, M. Naccarato, V. Amato, F. Contaldo, and F. Pasanisi. 2017. Prediction and evaluation of resting energy expenditure in a large group of obese outpatients. *International Journal of Obesity (2005)* 41(5):697-705.

McDuffie, J. R., D. C. Adler-Wailes, J. Elberg, E. N. Steinberg, E. M. Fallon, A. M. Tershakovec, S. A. Arslanian, J. P. Delany, G. A. Bray, and J. A. Yanovski. 2004. Prediction equations for resting energy expenditure in overweight and normal-weight black and white children. *American Journal of Clinical Nutrition* 80(2):365-373.

Most, J., L. A. Gilmore, A. D. Altazan, M. St Amant, R. A. Beyl, E. Ravussin, and L. M. Redman. 2018. Propensity for adverse pregnancy outcomes in African-American women may be explained by low energy expenditure in early pregnancy. *American Journal of Clinical Nutrition* 107(6):957-964.

Nielsen, S. B., J. J. Reilly, M. S. Fewtrell, S. Eaton, J. Grinham, and J. C. K. Wells. 2011. Adequacy of milk intake during exclusive breastfeeding: A longitudinal study. *Pediatrics* 128(4):e907-e914.

Nielsen, S. B., J. C. K. Wells, M. S. Fewtrell, S. Eaton, J. Grinham, and J. J. Reilly. 2013. Validation of energy requirement references for exclusively breast-fed infants. *British Journal of Nutrition* 109(11):2036-2043.

Nunes, C. L., N. Casanova, R. Francisco, A. Bosy-Westphal, M. Hopkins, L. B. Sardinha, and A. M. Silva. 2022a. Does adaptive thermogenesis occur after weight loss in adults? A systematic review. *British Journal of Nutrition* 127(3):451-469.

Nunes, C. L., F. Jesus, R. Francisco, C. N. Matias, M. Heo, S. B. Heymsfield, A. Bosy-Westphal, L. B. Sardinha, P. Martins, C. S. Minderico, and A. M. Silva. 2022b. Adaptive thermogenesis after moderate weight loss: Magnitude and methodological issues. *European Journal of Nutrition* 61(3):1405-1416.

Olivier, N., F. A. Wenhold, and P. Becker. 2016. Resting energy expenditure of black overweight women in South Africa is lower than of white women. *Annals of Nutrition and Metabolism* 69(1):24-30.

Park, M. Y., J. Kim, N. Chung, H. Y. Park, H. Hwang, J. S. Han, J. M. So, C. H. Lee, J. Park, and K. Lim. 2020. Dietary factors and eating behaviors affecting diet-induced thermogenesis in obese individuals: A systematic review. *Journal of Nutritional Science and Vitaminology* 66(1):1-9.

Parra, E. J., A. Marcini, J. Akey, J. Martinson, M. A. Batzer, R. Cooper, T. Forrester, D. B. Allison, R. Deka, R. E. Ferrell, and M. D. Shriver. 1998. Estimating African American admixture proportions by use of population-specific alleles. *American Journal of Human Genetics* 63(6):1839-1851.

Pereira, L. C. R., S. A. Purcell, S. A. Elliott, L. J. McCargar, R. C. Bell, P. J. Robson, C. M. Prado, and the Enrich Study. 2019. The use of whole body calorimetry to compare measured versus predicted energy expenditure in postpartum women. *American Journal of Clinical Nutrition* 109(3):554-565.

Poehlman, E. T. 1989. A review: Exercise and its influence on resting energy metabolism in man. *Medicine and Science in Sports and Exercise* 21(5):515-525.

Pontzer, H., Y. Yamada, H. Sagayama, P. N. Ainslie, L. F. Andersen, L. J. Anderson, L. Arab, I. Baddou, K. Bedu-Addo, E. E. Blaak, S. Blanc, A. G. Bonomi, C. V. C. Bouten, P. Bovet, M. S. Buchowski, N. F. Butte, S. G. Camps, G. L. Close, J. A. Cooper, R. Cooper, S. K. Das, L. R. Dugas, U. Ekelund, S. Entringer, T. Forrester, B. W. Fudge, A. H. Goris, M. Gurven, C. Hambly, A. El Hamdouchi, M. B. Hoos, S. Hu, N. Joonas, A. M. Joosen, P. Katzmarzyk, K. P. Kempen, M. Kimura, W. E. Kraus, R. F. Kushner, E. V. Lambert, W. R. Leonard, N. Lessan, C. Martin, A. C. Medin, E. P. Meijer, J. C. Morehen, J. P. Morton, M. L. Neuhouser, T. A. Nicklas, R. M. Ojiambo, K. H. Pietiläinen, Y. P. Pitsiladis, J. Plange-Rhule, G. Plasqui, R. L. Prentice, R. A. Rabinovich, S. B. Racette, D. A. Raichlen, E. Ravussin, R. M. Reynolds, S. B. Roberts, A. J. Schuit, A. M. Sjödin, E. Stice, S. S. Urlacher, G. Valenti, L. M. Van Etten, E. A. Van Mil, J. C. K. Wells, G. Wilson, B. M. Wood, J. Yanovski, T. Yoshida, X. Zhang, A. J. Murphy-Alford, C. Loechl, A. H. Luke, J. Rood, D. A. Schoeller, K. R. Westerterp, W. W. Wong, and J. R. Speakman. 2021. Daily energy expenditure through the human life course. *Science* 373(6556):808-812.

Pretorius, A., P. Wood, P. Becker, and F. Wenhold. 2021. Resting energy expenditure and related factors in 6- to 9-year-old southern African children of diverse population groups. *Nutrients* 13(6).

Quatela, A., R. Callister, A. Patterson, and L. Macdonald-Wicks. 2016. The energy content and composition of meals consumed after an overnight fast and their effects on diet induced thermogenesis: A systematic review, meta-analyses and meta-regressions. *Nutrients* 8(11).

Ravussin, E., S. Lillioja, T. E. Anderson, L. Christin, and C. Bogardus. 1986. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. *Journal of Clinical Investigation* 78(6):1568-1578.

Reilly, J. J., S. Ashworth, and J. C. K. Wells. 2005. Metabolisable energy consumption in the exclusively breast-fed infant aged 3–6 months from the developed world: A systematic review. *British Journal of Nutrition* 94(1):56-63.

Reneau, J., B. Obi, A. Moosreiner, and S. Kidambi. 2019. Do we need race-specific resting metabolic rate prediction equations? *Nutrition & Diabetes* 9(1):21.

Rush, E. C., L. D. Plank, and S. M. Robinson. 1997. Resting metabolic rate in young Polynesian and Caucasian women. *International Journal of Obesity and Related Metabolic Disorders* 21(11):1071-1075.

Rush, E. C., L. D. Plank, P. S. Davies, P. Watson, and C. R. Wall. 2003. Body composition and physical activity in New Zealand Maori, Pacific and European children aged 5-14 years. *British Journal of Nutrition* 90(6):1133-1139.

Saad, M. F., S. A. Alger, F. Zurlo, J. B. Young, C. Bogardus, and E. Ravussin. 1991. Ethnic differences in sympathetic nervous system-mediated energy expenditure. *American Journal of Physiology* 261(6 Pt 1):E789-E794.

Saito, M., M. Matsushita, T. Yoneshiro, and Y. Okamatsu-Ogura. 2020. Brown adipose tissue, diet-induced thermogenesis, and thermogenic food ingredients: From mice to men. *Frontiers in Endocrinology* 11:222.

Savard, C., A. Lebrun, S. O'Connor, B. Fontaine-Bisson, F. Haman, and A. S. Morisset. 2021. Energy expenditure during pregnancy: A systematic review. *Nutrition Reviews* 79(4):394-409.

Schutz, Y., and E. Jequier. 1998. Resting energy expenditure, thermic effect of food, and total energy expenditure. In *Handbook of obesity*, edited by G. A. Bray, C. Bouchard and W. P. T. James. New York: Marcel Dekker.

Schwartz, A., and E. Doucet. 2010. Relative changes in resting energy expenditure during weight loss: A systematic review. *Obesity Reviews* 11(7):531-547.

Schwartz, A., J. L. Kuk, G. Lamothe, and E. Doucet. 2012. Greater than predicted decrease in resting energy expenditure and weight loss: Results from a systematic review. *Obesity (Silver Spring)* 20(11):2307-2310.

Soares, M. J., L. S. Piers, K. O'Dea, and P. S. Shetty. 1998. No evidence for an ethnic influence on basal metabolism: An examination of data from India and Australia. *British Journal of Nutrition* 79(4):333-341.

Song, L. L., K. Venkataraman, P. Gluckman, Y. S. Chong, M. W. Chee, C. M. Khoo, M. K. Leow, Y. S. Lee, E. S. Tai, and E. Y. Khoo. 2016. Smaller size of high metabolic rate organs explains lower resting energy expenditure in Asian-Indian than Chinese men. *International Journal of Obesity (2005)* 40(4):633-638.

Spaeth, A. M., D. F. Dinges, and N. Goel. 2015. Resting metabolic rate varies by race and by sleep duration. *Obesity (Silver Spring)* 23(12):2349-2356.

Sun, M., B. A. Gower, T. R. Nagy, C. A. Trowbridge, C. Dezenberg, and M. I. Goran. 1998. Total, resting, and activity-related energy expenditures are similar in Caucasian and African-American children. *American Journal of Physiology* 274(2):E232-E237.

Sun, M., B. A. Gower, A. A. Bartolucci, G. R. Hunter, R. Figueroa-Colon, and M. I. Goran. 2001. A longitudinal study of resting energy expenditure relative to body composition during puberty in African American and white children. *American Journal of Clinical Nutrition* 73(2):308-315.

Tanaka, C., J. J. Reilly, and W. Y. Huang. 2014. Longitudinal changes in objectively measured sedentary behaviour and their relationship with adiposity in children and adolescents: Systematic review and evidence appraisal. *Obesity Reviews* 15(10):791-803.

Tershakovec, A. M., K. M. Kuppler, B. Zemel, and V. A. Stallings. 2002. Age, sex, ethnicity, body composition, and resting energy expenditure of obese African American and white children and adolescents. *American Journal of Clinical Nutrition* 75(5):867-871.

Thakkar, S. K., F. Giuffrida, C. H. Cristina, C. A. De Castro, R. Mukherjee, L. A. Tran, P. Steenhout, L. Y. Lee, and F. Destaillats. 2013. Dynamics of human milk nutrient composition of women from Singapore with a special focus on lipids. *American Journal of Human Biology* 25(6):770-779.

Toledo, F. G. S., J. J. Dubé, B. H. Goodpaster, M. Stefanovic-Racic, P. M. Coen, and J. P. DeLany. 2018. Mitochondrial respiration is associated with lower energy expenditure and lower aerobic capacity in African American women. *Obesity (Silver Spring)* 26(5):903-909.

Tranah, G. J., T. M. Manini, K. K. Lohman, M. A. Nalls, S. Kritchevsky, A. B. Newman, T. B. Harris, I. Miljkovic, A. Biffi, S. R. Cummings, and Y. Liu. 2011. Mitochondrial DNA variation in human metabolic rate and energy expenditure. *Mitochondrion* 11(6):855-861.

Walsh, M. C., G. R. Hunter, B. Sirikul, and B. A. Gower. 2004. Comparison of self-reported with objectively assessed energy expenditure in black and white women before and after weight loss. *American Journal of Clinical Nutrition* 79(6):1013-1019.

Wang, Z., Z. Ying, A. Bosy-Westphal, J. Zhang, B. Schautz, W. Later, S. B. Heymsfield, and M. J. Muller. 2010. Specific metabolic rates of major organs and tissues across adulthood: Evaluation by mechanistic model of resting energy expenditure. *American Journal of Clinical Nutrition* 92(6):1369-1377.

Watson, K. B., S. A. Carlson, D. D. Carroll, and J. E. Fulton. 2014. Comparison of accelerometer cut points to estimate physical activity in US adults. *Journal of Sports Sciences* 32(7):660-669.

Weinsier, R. L., G. R. Hunter, P. A. Zuckerman, D. T. Redden, B. E. Darnell, D. E. Larson, B. R. Newcomer, and M. I. Goran. 2000. Energy expenditure and free-living physical activity in black and white women: Comparison before and after weight loss. *American Journal of Clinical Nutrition* 71(5):1138-1146.

Westerterp, K. R. 2004. Diet induced thermogenesis. *Nutrition & Metabolism* 1(1):5.

White, K., J. A. Lawrence, N. Tchangalova, S. J. Huang, and J. L. Cummings. 2020. Socially-assigned race and health: A scoping review with global implications for population health equity. *International Journal for Equity in Health* 19(1):25.

WHO (World Health Organization). 2022. *Social determinants of health*. https://www.who.int/health-topics/social-determinants-of-health#tab=tab_1 (accessed December 8, 2022).

Wong, W. W., N. F. Butte, A. C. Hergenroeder, R. B. Hill, J. E. Stuff, and E. O. Smith. 1996. Are basal metabolic rate prediction equations appropriate for female children and adolescents? *Journal of Applied Physiology (1985)* 81(6):2407-2414.

Worsham, M. J., G. Divine, and R. A. Kittles. 2011. Race as a social construct in head and neck cancer outcomes. *Otolaryngology and Head and Neck Surgery* 144(3):381-389.

Wouters-Adriaens, M. P., and K. R. Westerterp. 2008. Low resting energy expenditure in Asians can be attributed to body composition. *Obesity (Silver Spring)* 16(10):2212-2216.

5

Development of Prediction Equations for Estimated Energy Requirements

To address its task to perform data analyses to validate and/or update the Estimated Energy Requirement (EER) equations, the committee commissioned an independent analysis of databases of doubly labeled water (DLW) measures of energy expenditure in population groups. A report summarizing the consultant's work is presented in Appendix G, and the expanded details are provided in Supplemental Appendixes N to W.[1] To validate the results from the commissioned analysis, the committee conducted a review of the peer-reviewed published literature not included in the analyzed databases. Further, the committee identified additional data from systematic reviews and the broader peer-reviewed published literature on evidence to determine the energy cost of growth across selected life stages (childhood, adolescence, pregnancy, and lactation). The committee synthesized all information used to derive Estimated Energy Requirements, which are presented at the end of this chapter (Tables 5-15 through 5-18) for all life-stage groups relevant to the Dietary Reference Intakes (DRIs). Applications of the equations for individuals and groups are discussed in Chapter 7.

USE OF DOUBLY LABELED WATER TO ASSESS ENERGY REQUIREMENTS

Adequate dietary intake of energy is critical for optimal cellular and body functions, growth, pregnancy outcomes, and lactation performance.

[1] Supplemental appendixes are available at https://nap.nationalacademies.org/catalog/26818.

Determination of dietary energy intake requirements relies on the ability to accurately measure energy intake. Many methods are available to assess dietary energy intake (Lam and Ravussin, 2016), although accuracy and precision vary considerably by method. Until the widespread adoption of the DLW method, described below, determination of EERs for humans across the life span relied on less accurate and less precise measures (FAO, 2004).

Common methods for assessing dietary energy intake rely on self-reported food intakes, such as from 24-hour dietary recalls, food diaries, and food frequency questionnaires. Prior to the 2004 Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU) report on human energy requirements, recommendations for energy intake were based on data obtained using the factorial method of estimating energy expenditure (FAO, 2004). The factorial method involves summing the energy costs of occupational activities, nonoccupational activities, and sleeping to equal total energy expenditure (WHO, 1985). The method involves multiple assumptions about representative daily activities across the life span. This method of estimating energy expenditure and, by extension, energy intake was the best option for the determination of energy requirements prior to the use of DLW in humans.

The DLW method is considered by the nutrition community to be the benchmark standard for measurement of total energy expenditure (TEE) in humans under free-living conditions. The DLW method involves enrichment of the body water with the natural, nonradioactive isotopes of deuterium (^{2}H) and oxygen-18 (^{18}O). The disappearance rate of ^{2}H from the total body water pool reflects water turnover rate, and the disappearance rate of ^{18}O reflects both water and carbon dioxide turnover rates. The difference between the two turnover rates represents the carbon dioxide production rate (Black et al., 1986; Speakman et al., 2021), and carbon dioxide production is one of the final products of energy metabolism. The rate of carbon dioxide production can then be converted to TEE using Weir's equation (Weir, 1949).

The DLW method has several desirable features when compared to the other methods for measuring energy expenditure under free-living conditions. First, it imposes zero restriction or interference with participants' daily activities and eating habits; participants need only drink a small amount of water labeled with the two isotopes, ^{2}H and ^{18}O. Second, the method is noninvasive because it requires only collection of spot urine samples. Third, the method is robust and portable; the DLW procedure can be implemented anywhere. Fourth, the duration of the DLW procedure is flexible and can be implemented between 7 and 14 days. This flexibility allows for a more representative measure of the actual energy expenditure because the duration can, for example, include weekend days, when activities and food intakes might be different than those during weekdays. Fifth, since the two isotopes are naturally occurring and are found naturally in the water, foods, and beverages that people consume every day, the method can be safely implemented in humans with no adverse effects, including premature infants, newborns, toddlers, teenagers, aged individuals, and pregnant and lactating women.

Critically, accuracy of the DLW method has been validated against indirect calorimetry (Klein et al., 1984; Melanson et al., 2018; Ravussin et al., 1991; Schoeller and Webb, 1984; Schoeller et al., 1986; Seale et al., 1993; Westerterp et al., 1988). Furthermore, TEE measurements using the DLW method have also been documented to be reproducible over a 4-year period (Wong et al., 2014), allowing evaluation of long-term effects of nutritional, physical, and medical interventions and treatments. Both the 2004 FAO/WHO/UNU and the Institute of Medicine (IOM) (2002/2005) energy requirement recommendations depended on DLW data to develop the respective EERs. A comparison of EERs for infants between the FAO/WHO/UNU 1985 report and its 2004 report found significantly lower requirements based on DLW data than were proposed by the factorial method (FAO, 2004). Energy requirements of infants in the FAO/WHO/UNU 1985 report were estimated from dietary intake studies, which are prone to overestimation.

The DLW method provides an objective measurement of TEE integrated over days, if not weeks, and in combination with basal metabolism measured using indirect calorimetry, it allows for the objective measurement of energy expended in physical activity. As illustrated in Chapter 4 (Figure 4-1), TEE comprises basal (or resting) metabolic rate (BMR), thermic effect of food (TEF), and physical activity level (PAL). Energy expended in physical activity, therefore, can be calculated as the difference between TEE and BMR plus TEF (generally accepted to be approximately 10 percent of TEE) (Schutz and Jequier, 1998). In this report, BMR refers to the energy required when the human body is at complete physical, mental, and digestive rest (see Chapter 4, Table 4-1). Physical activity can also be expressed as the ratio of TEE-to-BMR, referred to as the physical activity level, or PAL. The inclusion of BMR in this expression allows for some adjustment for body size, as BMR is highly dependent on height and body weight (Butte and Caballero, 2014). The DLW method provides for objective measures of TEE and physical activity.

Relationship Between TEE and EER

In a weight-stable person, TEE is the most accurate measure of a person's EER. For a growing individual, such as an infant or a child, EER is the sum of TEE and the energy cost of growth (ECG). The ECG can be calculated from the energy contained in tissue deposited during growth phases, based on the proportion of protein and fat being deposited in the new tissues. For a pregnant woman, particularly during the second and third trimesters, EER is the sum of TEE and the energy cost of tissue accretion during pregnancy in both the fetal and maternal tissues. For a lactating woman, EER is the sum of TEE and the energy cost of milk production. For children and adolescents between 3 and 18 years of age, the ECG represents a small increase above TEE, merely 1 to 3 percent of TEE. For a pregnant woman, the energy cost of tissue accretion represents approximately 10 percent above TEE. For a lactating woman, the energy cost of milk production is approximately 15 to 20 percent of TEE, depending on the amount of milk volume and milk energy content. In contrast, among infants under 1 year of age, ECG could be as high as 32 percent of TEE.

Because TEE comprises basal energy expenditure, energy expenditure for physical activities, and the thermic effect of food, an accurate measure of TEE would provide a good approximation of EER, with additions for the life stages of growth, pregnancy, and lactation. The committee noted the uniqueness and value of the DLW method for measuring TEE compared to other measures of energy expenditure. Based on the large number of DLW studies that have become available since the prior update to the DRIs for energy (IOM, 2002/2005), the sponsors asked the committee to reevaluate the EER of the general population in the United States and Canada using DLW data that were not available at the time of the 2002/2005 report.

ACQUISITION OF DOUBLY LABELED WATER DATA

The combined DLW database described in this chapter was composed of data obtained from the International Atomic Energy Agency (IAEA), the Institute of Medicine (IOM, 2002/2005), the National Heart, Lung, and Blood Institute (NHLBI), Biologic Specimen and Data Repository Study of Latinos: Nutrition & Physical Activity Assessment Study (SOLNAS), and the Children's Nutrition Research Center at the Baylor College of Medicine (CNRC) (Appendix H). The pregnancy data sets were harmonized and then combined with the other three data sets, resulting in 8,722 observations. After removing implausibly high TEEs and PALs, the combined data set had 8,600 observations including all ages, as well as pregnant and lactating women.

IAEA DLW Database

The IAEA DLW Database represents the largest collection of DLW data globally. This database (version 3.6.1) consists of 128 DLW studies from 25 countries with 7,696 data points (4,987 females and 2,709 males). The idea to gather data from DLW studies around the world was first discussed during the 3rd International Conference on Recent Advances and Controversies in the Measurement of Energy Metabolism 2014, held in Tokyo, Japan. The agreement among the major users to create the collaborative DLW database was finalized in 2015, and in 2016, IAEA agreed to host the database. In 2018, the IAEA DLW Database website was finalized, granted web security at IAEA, and officially launched. The IAEA DLW Database has an informal management group that approves requests for data acquisition.[2]

The National Academies of Sciences, Engineering, and Medicine (National Academies) consultants (Indiana University School of Public Health-Bloomington) submitted a request for data for the present analyses. Variables including participant identifier (ID), study ID (i.e., citation for published works and lead investigator for unpublished work), age, sex, body mass index (BMI), height, weight at the beginning of the DLW study period, TEE, fat-free mass, fat mass, percent fat mass, BMR, method of BMR measurement, and international standard country codes were requested with no *a priori* exclusions.

The majority of the observations included in the IAEA DLW Database came from studies in the United States (78.1 percent), followed by Europe (4.8 percent); there were no DLW studies from Canada. The majority of these DLW studies were published in peer-reviewed journals between 1982 and 2020. To corroborate the data reported in the IAEA database, a literature search was carried out based on the lead author and year of publication; a full copy of each publication was retrieved. Each publication was used to verify health status and athletic or military involvement of the study participants. The publication also helped to confirm the data were collected as reported—at baseline or prior to treatment in intervention studies. Because the committee was charged with defining EERs for the general population, the following exclusion criteria were established following consensus among committee members:

- Studies from non-high-income countries were excluded because the living, health care, and physical activity environments, as well as food availability in low- and middle-income countries, might be very different from those in high-income countries such as the United States and Canada; thus influencing calculation of the EERs.
- Study participants with genetic, infectious, and health conditions such as Down syndrome, Prader-Willi syndrome, human

[2] https://doubly-labelled-water-database.iaea.org (accessed February 8, 2023).

immunodeficiency virus (HIV) infection, anorexia nervosa, narcolepsy, Parkinson's disease, cystic fibrosis, chronic obstructive pulmonary disease, coronary heart disease, and diagnosed Type 1 diabetes, other non-communicable diseases such as Type 2 diabetes, as well as postsurgical patients, including bariatric surgery, were excluded because these conditions may affect TEE and EERs.

- Athletes such as soccer players, rugby players, and jockeys were excluded from analysis because their extremely high physical activity levels (PAL greater than 2.5) do not reflect a sustainable metabolic rate (Black et al., 1996; Westerterp, 2001).
- Study participants who took part in strenuous physical activities specifically during the DLW measurement period, such as intensive military training, climbing Mt. Everest, running marathons, cross-country ski racing, or multiday cycling, were excluded from analysis with the same reasoning for athletes.
- Premature infants were excluded from analysis.
- Data following weight loss, exercise, or dietary interventions were excluded; only baseline data were included, where available.
- Institutionalized older adults were excluded because of potential unidentified health concerns, as well as limited mobility.

As indicated above, the IAEA DLW Database began with 7,696 study participants; after excluding 707 from non-high-income countries, 239 with infectious and chronic diseases, 50 professional athletes and study participants who took part in strenuous physical activities during the measurement period, 673 institutionalized elders, 222 observations with no age or sex reported, and 88 study participants with PAL greater than 2.5, there were 5,717 observations available for DRI analysis. The ages of the study participants included in the final IAEA dataset ranged from 0 to 90 years and above.

SOLNAS DLW Database

The Hispanic Community Health Study/Study of Latinos is the largest cohort of Hispanics being followed in the United States. The study, funded by the NHLBI and other NIH institutes, recruited 16,415 individuals from randomly selected households. Baseline (wave 1) of data collection (2008–2011) included protocols similar to those of the National Health and Nutrition Examination Study (NHANES) (Mossavar-Rahmani et al., 2015; Sorlie et al., 2010). An ancillary study was carried out between 2010 and 2012 for the purpose of calibrating random and systematic bias of self-reported dietary and physical activity behaviors that included the use of DLW called the Study of Latinos: Nutrition and Physical Activity

Assessment Study (SOLNAS) (Mossavar-Rahmani et al., 2015). This study was conducted in the four field centers located in major U.S. cities, with a goal of recruiting 120 persons from each center: Chicago, Illinois; Miami, Florida; Bronx, New York; and San Diego, California and was supported by a coordinating center at the University of North Carolina at Chapel Hill.

Protocols were implemented in 485 participants in the Hispanic Community Health Study by trained and certified staff that consisted of weight measurements, completing a 24-hour recall, reporting on current supplement use and sedentary activity, receiving a single dose of DLW, spot urine tests, 24-hour urine specimens, and for those over 60 years of age a blood specimen (Mossavar-Rahmani et al., 2015). In a subsample of 96 participants, protocols were repeated for a reliability study. All study participants were invited to participate within 7 months of completing the baseline exam. Ages of the study participants ranged between 18 and 74 years, and all self-identified as Hispanic/Latino, representing Central American, Cuban, Dominican, Mexican, Puerto Rican, and South American ancestry.

Data from SOLNAS are publicly available on NHLBI's Biological Specimen and Data Repository Information Coordinating Center (BIOLINCC) site.[3] The National Academies requested use of the data on behalf of the Indiana University consultants. Requested variables included age, sex, starting weight, height, BMI, ethnicity, final weight, lean body mass, physical activity, smoking status, and health status. See Appendix H, Box, H-1 for the full list of requested data sets and variables. After exclusion of individuals with medical conditions, data on 380 study participants (157 males and 223 females) were included in the analysis.

IOM DLW Database

The IOM (2002/2005) report included DLW data that were available to the committee and published by the end of the year 2000; the data pertained to study participants with normal weight, overweight, and obesity, as well as pregnant and lactating women. For the present analyses, these data were added to the IAEA and the SOLNAS data after removing data with PAL values greater than 2.5 or in the case of infants, a PAL less than 1.0. The IOM (2002/2005) database consisted of 1,145 observations on infants and children between 0 and 18.99 years of age; 842 observations on adults 19 years of age or older with normal weight, overweight, or obesity; and 173 observations on pregnant women and 123 on lactating women, for a total of 2,283 study observations. The number of pregnant and lactating women with DLW data was relatively limited, and participants with body mass indices less than 18.5 were excluded from analyses.

[3] https://biolincc.nhlbi.nih.gov/home/ (accessed February 8, 2023).

CNRC DLW Database

To augment the number of DLW observations of pregnant and lactating women to define the EER for pregnancy and lactation, the committee obtained DLW data on 63 women studied longitudinally from preconception, during the second and third trimesters of pregnancy, and 6 months postpartum at the Children's Nutrition Research Center (CNRC) at Baylor College of Medicine, providing 220 observations for analysis after removal of data with PAL values greater than 2.5.

Combined DLW Database

As shown in Table 5-1, a total of 8,600 study participants or individual observations were identified from these DLW databases following the exclusions described.

The combined DLW data set used to generate equations for EERs comprised a total of 8,600 observations representing the major human life stages. DLW data on pregnant, lactating, and non-pregnant non-lactating (NPNL) women were derived from longitudinal studies. Among pregnant women, the majority of measurements were made during the second and third trimesters, 35.1 percent and 36.2 percent, respectively, of the total number of observations. The total number of observations also include measurements made at preconception (23.2 percent). Approximately 50 percent of the measurements among lactating women were made between

TABLE 5-1 Distribution of Observations by Life Stage and DLW Database

Life Stages	IAEA	SOLNAS	IOM, 2002/2005	CNRC	Totals
Infants, 0–11 months	378	0	177	0	555
Children, 1–8 years	432	0	689	0	1,121
Children, 9–18 years	425	0	279	0	704
Adults, 19+ years	4,309	380	767	0	5,456
Pregnant/lactating/ NPNL women	173	0	371	220	764
Totals	5717	380	2,283	220	8,600

NOTES: IAEA = International Atomic Energy Agency; SOLNAS = Study of Latinos: Nutrition and Physical Activity Assessment Study; IOM = Institute of Medicine; CNRC = Children's Nutrition Research Center at Baylor College of Medicine; NPNL = nonpregnant nonlactating women who were included in the studies of pregnant or lactating women. DLW data on pregnant, lactating, and NPNL women represent repeated measures derived from longitudinal studies.

1 and 3 months postpartum, and the other 50 percent between 4 and 6 months postpartum. Descriptive characteristics of the participants in the combined DLW data set are in Table 5-2, and more detailed descriptive statistics are in Appendix H.

TABLE 5-2 Descriptive Characteristics by Life Stage in Combined DLW Data Set

	Life Stage				
	Infants 0–11 mo	Children 1–8 y	Children 9–18 y	Adults 19+ y	Pregnant/lactating/NPNL women
Total number of subjects	555	1,121	704	5,456	764
Female (n)	320	634	434	3,585	764[d]
Female (%)	57.7	56.6	61.6	65.7	100
Age (y), Mean (SD)	0.39 (0.26)	5.1 (2.1)	13.7 (3.1)	52.6 (19.7)	30.0 (4.2)
Height[a] (cm), Mean (SD)	63.4 (6.7)	10.4 (16.2)	159.0 (15.4)	167.0 (9.7)	164.3 (6.5)
Weight (kg), Mean (SD)	6.8 (1.8)	21.3 (8.0)	55.8 (17.0)	75.7 (17.1)	73.7 (20.1)
Fat-free mass (kg), Mean (SD)	4.7 (1.1)	14.2 (4.2)	43.0 (11.5)	47.7 (10.4)	56.3 (9.6)
n^b	376	431	423	4,659	173
Fat mass (kg), Mean (SD)	1.7 (0.8)	5.4 (3.4)	18.1 (19.9)	28.1 (11.4)	44.9 (12.0)
n^b	375	431	423	4,652	173
Fat mass (%), Mean (SD)	25.1 (7.2)	26.4 (6.9)	28.8 (9.7)	36.3 (9.3)	43.9 (6.1)
n^b	375	431	423	4,652	173
Percentile[c]	51.2 (28.0)	60.3 (28.1)	63.7 (26.0)	—	—
TEE (kcal/d), Mean (SD)	504 (171)	1,392 (370)	2,491 (668)	2,437 (592)	2,531 (472)
BMR (kcal/d), Mean (SD)	457 (93)	966 (205)	1,454 (319)	1,487 (308)	1,478 (225)
n^b	164	487	354	2,364	582

NOTE: BMR = basal metabolic rate; cm = centimeter; d = day; mo = months; kcal = kilocalorie; kg = kilogram; n = sample size; NPNL = nonpregnant nonlactating; SD = standard deviation; TEE = total energy expenditure; y = years.

[a] Height equivalent to length in infants.

[b] Sample sizes (n) indicated for variables with significant missing data.

[c] Weight-for-length percentile (WHO) calculated for children 0–1.99 years; BMI percentile (Centers for Disease Control and Prevention [CDC]) calculated for children 2–18 y.

[d] Sample size does not represent unique observations.

DERIVATION OF TOTAL ENERGY EXPENDITURE PREDICTION EQUATIONS

General Approach to Develop Prediction Equations for Total Energy Expenditure

When the combined DLW database was assembled and graphically displayed (see Appendix G and Supplemental Appendixes N to W for a detailed description of database assembly and full statistics), it was apparent that TEE changed in a curvilinear manner across the life span. To address this curvilinearity, the committee developed sex-specific TEE prediction equations for infants and young children (0 to 2.99 years), children (3.0 to 18.99 years), and adults (19.0+ years). A separate TEE prediction equation was developed for pregnant women.

An integral and highly variable component of TEE, and therefore of TEE prediction equations, is energy expended in physical activity. The original EERs (IOM, 2002/2005) accounted for variability in physical activity by incorporating PAL, representing four categories as sedentary, low active, active, and very active as a variable in the modeling. The same PAL thresholds were used to define the categories across all life stages except infancy. From the graphic display of the current data, however, it was apparent that the mean PAL value was age dependent in the first 2 decades of life, and the same PAL coefficients could not be used for all life stages. An approach was needed to incorporate the age dependency into PAL categories for the development of the TEE prediction equations.

Another major question that arose was whether separate equations were warranted for select BMI groups, as was done in the previous report on energy and macronutrients (IOM, 2002/2005). To address this question, separate TEE prediction equations were developed for normal weight and overweight/obesity and tested for significant differences in coefficients at the 2-tailed 0.05 α level. Also, prediction equations based on anthropometric variables, weight, and height were compared against body composition variables, fat-free mass (FFM), and fat mass (FM).

Statistical Methods

Database Preparation

The committee's database provided the following variables: TEE, age category, age, sex, life stage, race/ethnicity, BMI, height, weight, BMR observed, BMR predicted, lactating, pregnant, pregnancy stage, gestational weeks, PAL observed, PAL category observed, PAL predicted, PAL category predicted, FFM, FM, and FM percent.

BMI categories were applied to classify participants into a select weight-for-length percentile, BMI percentile, or BMI group. For infants and children (0 to 2 years), weight-for-length percentiles were based on the WHO (2022) expanded tables. For children 2 to 18 years of age, BMI percentiles were calculated based on age/sex-specific growth charts from the Centers for Disease Control and Prevention (CDC, 2009). For adults, BMI cutoffs defined as underweight (BMI < 18.5), normal weight (BMI 18.5 to < 25), overweight (BMI 25.0 to 29.9), and obese (BMI ≥ 30.0) were used (NHLBI/NIDDK, 1998; WHO, 1998).

A measure or estimate of BMR is required to calculate PAL. In the combined DLW database, BMR was missing for more than 50 percent of the observations. Thus, two methods were used to account for missingness: use of prediction equations and multiple imputation. An examination of existing systematic reviews was undertaken to identify the most appropriate equation(s) for the estimation of BMR for use in the analyses (see Appendix D for a description of the literature search criteria and outcomes). The identified prediction equations were evaluated based on the reported percentage of bias [(mean measured BMR – mean predicted BMR)/mean measured BMR × 100], precision (percentage of participants with predicted BMR within 10 percent of measured BMR), and/or R^2 values. The committee decided to use the sex- and age-specific Schofield equations based on weight and height to estimate BMR where the value was missing in the combined DLW database (Schofield, 1985), and an estimated PAL was calculated accordingly. Participants with observed or estimated values of PAL greater than 2.5 were considered unsustainable and removed from the database. Values of PAL less than 1.0 are nonphysiological and were made missing to be imputed and bounded at 1.0.

Multiple Imputation

Multiple imputation was used to estimate missing data based on the other measures in the database. The imputation used the observed BMR values and the estimated BMR values from the Schofield equations as proxy variables, because the Schofield values are highly correlated with the true BMRs that are being imputed, thereby improving the precision of the imputation. In multiple imputation, missing data are imputed by randomly generating multiple values consistent with the multivariate distribution of observed data (Little and Rubin, 2019). The SAS software (version 9.4, SAS Institute, Cary, NC) procedure Proc MI was used with Markov Chain Monte Carlo methods with multiple chains, using 20 imputations. For the combined analysis data set (n = 8,600), all missing data for all variables in the data set were simultaneously imputed (e.g., PAL, FM, FFM) providing 20 versions of a complete data set. Statistical models were then fit on each version of the data set, and the results were pooled using Rubin's methods (Rubin, 1987) in SAS Proc MIanalyze (see Appendix G and supplemental appendixes).

STATISTICAL MODELING: DEVELOPMENT OF TEE PREDICTION EQUATIONS

Prediction equations were developed fitting general linear models on TEE based on sex, age, weight, height, and PAL category, or, alternatively, based on sex, age, height, body composition variables (FFM and FM), and PAL category. For the pregnancy equations, the number of gestational weeks was included as an additional variable. Analysis of pregnancy data included longitudinal data for women at multiple time points. In this case, linear mixed models were performed with Proc Mixed in SAS using a repeated statement to account for correlation of data within women. In sum, TEE models were fit separately for each of the following strata: boys (0 to 2.99 years), girls (0 to 2.99 years), boys (3.0 to 18.99 years), girls (3.0 to 18.99 years), men (19+ years), women (19+ years), and pregnant women.

TEE prediction models were fit for all available data within each stratum, as well as for subsets based on select BMI criteria (BMI group): BMI 18.5 to 40 (sensitivity, removing extremes BMI < 18.5 and > 40); BMI 18.5 to < 25 (normal weight only); and BMI ≥ 25 (overweight/obesity only). The five resultant prediction equations, model performance, and model comparisons are shown in detail in Appendix G and the supplemental appendixes. In this chapter, the TEE prediction equation using all available data within each stratum is presented. In Appendix G, detailed analyses are provided for the five models: all-included model, sensitivity model, normal weight BMI model, overweight/obese BMI model, and fat-free mass/fat mass model.

In all TEE prediction equations except those for children 0 to 2 years of age, a four-level ordinal variable was used to represent PAL category (PALCAT). Given the age dependency of PAL, the cutoffs for inactive, low active, active, and very active levels of physical activity were defined for specific age groups, based on observed data.

TEE was modeled as a function of age, weight, height, and PAL category as predictors and also included interactions of PAL category with height and weight as follows:

$$\mathbf{TEE = Intercept + A \times Age\ (years) + B_0 \times Height\ (cm) + C_0 \times Weight\ (kg) + D_{\mathit{i}} \times PALCAT_i + B_{0I} \times PALCAT_i \times Height\ (cm) + C_{0I} \times PALCAT_i \times Weight\ (kg) + error}$$

where $PALCAT_i$ represents 3 indicator variables for PAL category (Active, Low Active, Inactive) that are coded as 0 or 1; 'A', 'B_0', 'C_0', and 'D_i'

are the model coefficients for the main effects of age, height, weight and the 3 PAL categories, respectively; and 'B_{0I}' and 'C_{0I}' are the model coefficients for the interaction of the 3 PAL categories with height and weight, respectively. (The full model output including all the coefficients for interaction terms of height and weight by PAL category are provided in Supplemental Appendix Q; Details on the redefining of the TEE model are provided in the addendum to Appendix G.) For simplicity and ease of use, the TEE prediction equation is presented by redefining the parameters of the model above with slopes for height and weight separately for each PAL category in the following format:

Predicted TEE = Intercept + A × Age (years) + B × Height (cm) + C × Weight (kg)

In this equation 'A,' 'B,' and 'C' are the model-derived coefficients for the slopes of Age, Height, and Weight, respectively, for each PAL category. (The details of how the model is redefined is described in an addendum to Appendix G.) Slopes for height and weight are each allowed to vary by PAL category, whereas the slope for Age remains constant.

The 2005 EER could also computed by PAL category, and, as in the equation above, the coefficient for Age did not vary by PAL category. However, unlike the equation above, the intercept also did not vary by PAL category, and, although the coefficients for Height and Weight varied by PAL category, they were multiplied by the same PAL coefficient, whereas in the equation above, the parameters represent a deviation from the overall slope, which is not restricted to be the same for Height and Weight. A comparison of the EER values from 2005 and this report is presented in Chapter 7.

In addition, the TEE prediction equations for normal weight BMI and overweight/obesity BMI were compared further using three-way interaction terms with BMI group. This allowed comparison of the slopes of height and weight between normal weight BMI and overweight/obesity BMI, within each PAL category.

Race/ethnicity was not included as a covariate in any of the analyses associated with the development of the EERs due to the magnitude of missing data across the life stages. Among infants, 59.5 percent of observations were missing race/ethnicity; among children, 75.4 percent; among adolescents, 52.3 percent; and among adults, 21.8 percent.

Model Performance: Model Fit

Model fit was evaluated for the TEE prediction equations (all-included, sensitivity, normal weight BMI, overweight/obesity BMI, FFM/FM), broken down by strata (boys 0–2 years, girls 0–2 years, boys 3–18 years, girls 3–19 years, men 19+ years, women 19+ years, and pregnant women) comparing predicted values of TEE from the final equations to the observed data for TEE. The summary statistics include sample sizes, R^2, adjusted R^2, shrunken R^2 (Browne formula; Yin and Fan, 2001), Pearson *r* correlation, mean square error (MSE), mean absolute percentage error (MAPE), and mean absolute error (MAE). MAPE and MAE describe the average difference between the observed and predicted values of TEE in either percent difference or absolute difference, respectively, where MAE is in units of kcal/day. Bland-Altman plots were used to visualize the difference between observed and predicted TEE values (Myles and Cui, 2007). Details are provided in Appendix G and the supplemental appendixes.

Prediction Error

TEE was predicted for an individual at the average levels of age, height, and weight with an active PAL in each strata, along with the standard error (SE) of the predicted values. A 95 percent prediction interval can be calculated using the predicted value ±1.96 × SE, such that there is a 95 percent probability that a future observation of TEE for someone at the same levels of covariates will be contained within the prediction interval.

RESULTS

Statistical Modeling: Development of TEE Prediction Equation

As seen in Figure 5-1, TEE measured by the DLW method increased sharply in infancy, continued to rise during childhood, and plateaued through adulthood with a gradual decline in older adults. This curvilinear pattern motivated the age strata used to develop the TEE prediction equations. Within the specific strata, TEE clearly increased across the BMI categories, as seen in adults in Figure 5-2.

Physical Activity Categories

The graphic display of PAL as a function of age demonstrated a curvilinear pattern, justifying the need to define PAL categories by age group (Figure 5-3).

To derive the age-specific PAL categories for children, the committee examined PAL quartiles by age. Histograms (Figure 5-4) of the distribution of PAL values by age groups and BMI status showed that the data were approximately symmetric for most subgroups, except among children 0 to 2.99 years, for whom the median PAL values were about 1.3. Consequently,

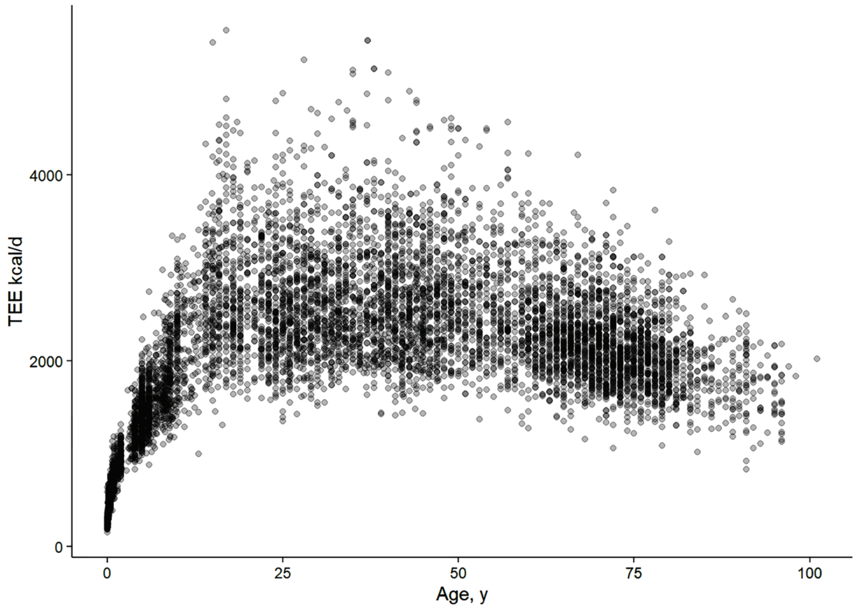

FIGURE 5-1 Observed TEE (kcal/d) as a function of age (y) derived using data from the DLW database.
NOTE: TEE = total energy expenditure.

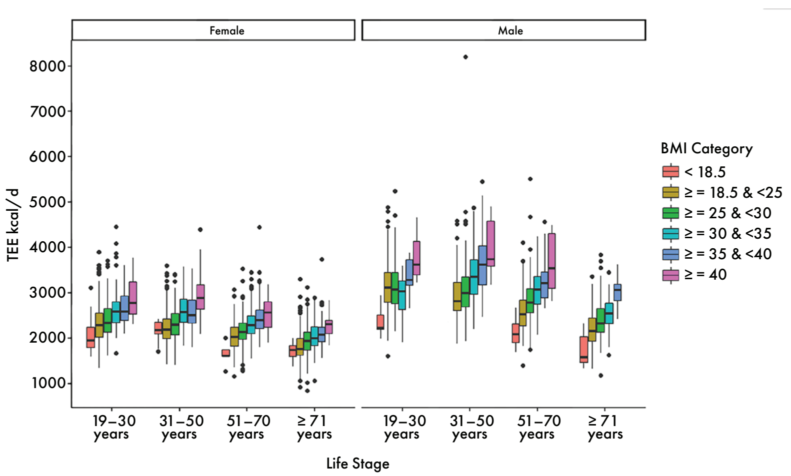

FIGURE 5-2 TEE (kcal/d) by BMI category for men and women, 19 years of age and over.
NOTES: BMI = body mass index; kg = kilogram; m = meter; TEE = total energy expenditure. Some categories do not have both upper and lower limits.

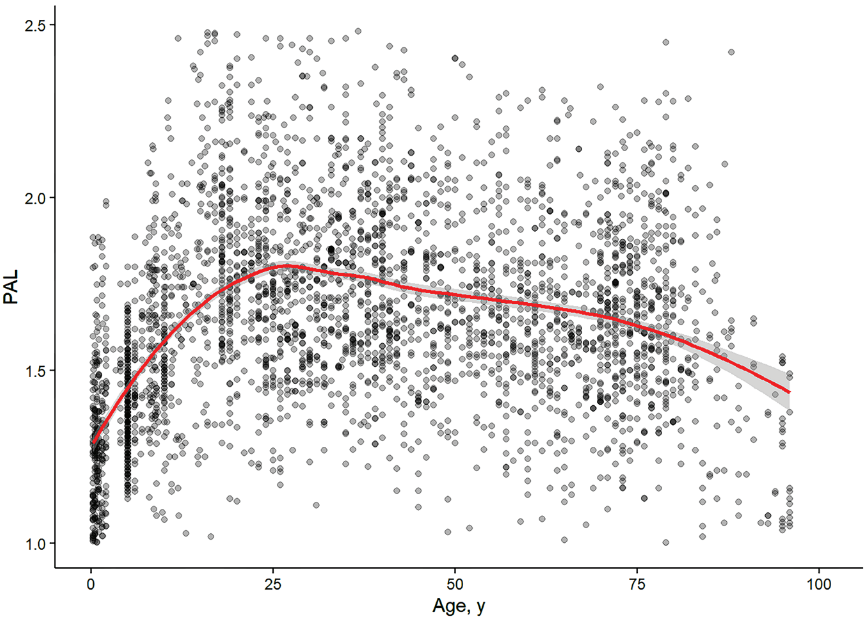

FIGURE 5-3 Physical activity level values displayed as a function of age (y).
NOTE: PAL = physical activity level.

PAL categories were not incorporated into the prediction equations for infants and children 0 to 2.99 years because of their limited range of physical activity. For age groups 3 to 8.99 years, 9 to 13.99 years, and 14 to 18.99 years, the committee opted to use percentiles (25, 50, and 75). For adults, PAL categories (based on observed data plus predicted data) were defined by percentiles (25, 50, 75) for 19 to 70 years; these PAL categories were then applied to adults of all ages (Table 5-3).

The PAL categories are defined as inactive, low active, active, and very active for age groups 3 to 8.99 years, 9 to 13.99 years, 14 to 18.99 years, and 19 years and over (Table 5-4). PAL is a complex aggregate of lifestyle dependent on occupation, transportation, recreation, sleep patterns, and environmental factors. In general, the inactive category reflects a level of TEE covering basal metabolism, thermic effect of food, and a minimal level of physical activity required for independent living. The low active category reflects a level of physical activity beyond the minimal, involving more ambulation, and some occupational and recreational activities. The active category involves even more ambulation, and occupational or recreational activities. The very active category encompasses not only the demands of daily living but also vigorous exertion in occupation or recreation.

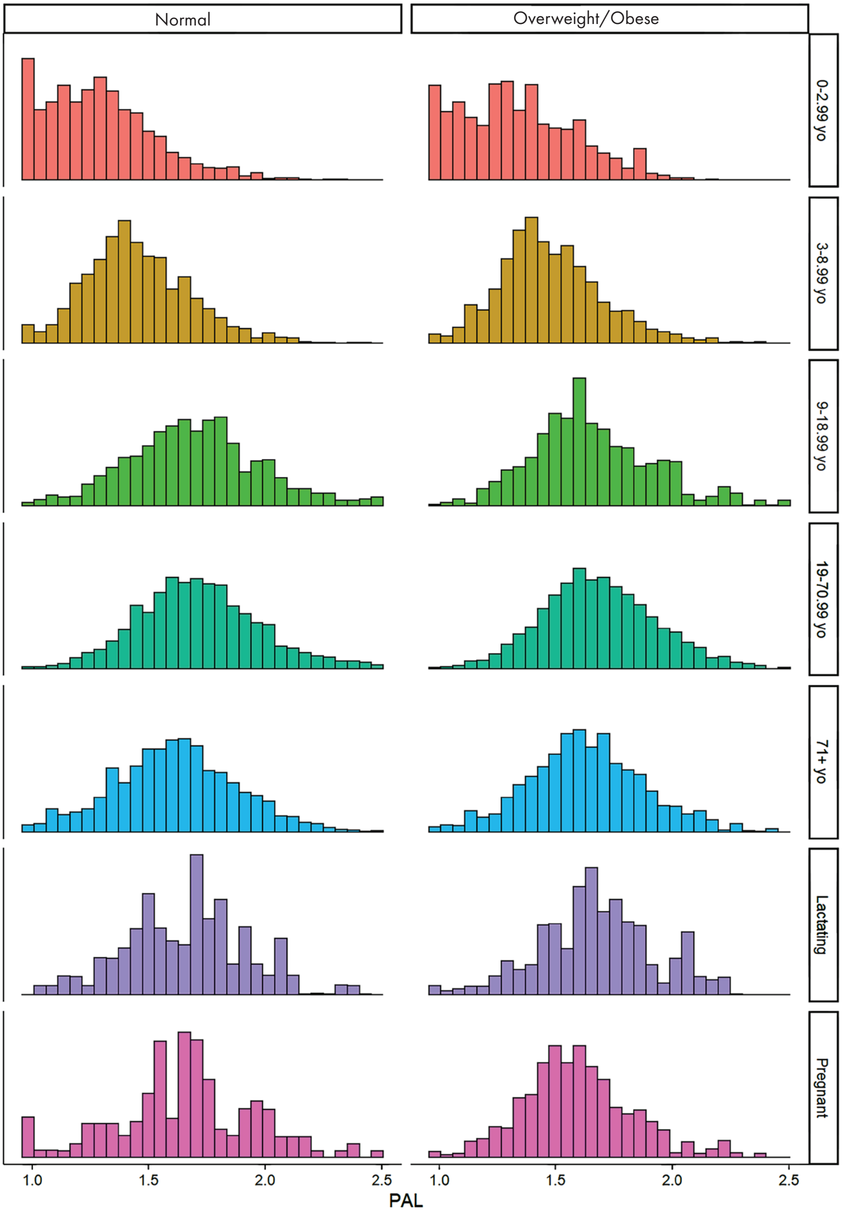

FIGURE 5-4 Histograms of physical activity level (PAL) presented by body mass index (BMI) category (normal BMI or overweight/obese BMI) by life stage. While most of the distributions appear normal, others are less smooth primarily due to small sample sizes.

TABLE 5-3 PAL Percentiles for Age Groups Used to Define the Cutoffs for Inactive, Low Active, Active, and Very Active Physical Activity Level (PAL) Categories

Percentile	0–2.99 years n = 750	3–8.99 years n = 926	9–13.99 years n = 304	14–18.99 years n = 403	19–70.99 years n = 4,299	71+ years n = 1,281
10%	1.00	1.20	1.29	1.40	1.39	1.31
25%	1.11	1.31	1.44	1.56	1.53	1.46
50%	1.27	1.44	1.59	1.73	1.68	1.62
75%	1.44	1.59	1.77	1.92	1.85	1.79
90%	1.61	1.75	1.92	2.11	2.03	1.95

TABLE 5-4 Physical Activity Level (PAL) Categories Defined for Inactive, Low Active, Active, and Very Active Levels for Age Groups 3–8.99 Years, 9–13.99 Years, 14–18.99 Years, and 19 Years and Over

Age Group (years)	PAL Category	PAL Range
3–8.99	Inactive	$1.0 \le PAL < 1.31$
	Low active	$1.31 \le PAL < 1.44$
	Active	$1.44 \le PAL < 1.59$
	Very active	$1.59 \le PAL < 2.50$
9–13.99	Inactive	$1.00 \le PAL < 1.44$
	Low active	$1.44 \le PAL < 1.59$
	Active	$1.59 \le PAL < 1.77$
	Very active	$1.77 \le PAL < 2.50$
14–18.99	Inactive	$1.00 \le PAL < 1.56$
	Low active	$1.56 \le PAL < 1.73$
	Active	$1.73 \le PAL < 1.92$
	Very active	$1.92 \le PAL < 2.50$
19 and over	Inactive	$1.00 \le PAL < 1.53$
	Low active	$1.53 \le PAL < 1.68$
	Active	$1.68 \le PAL < 1.85$
	Very active	$1.85 \le PAL < 2.50$

The general model performed to predict TEE used age, height, weight, and PAL category as predictors and also included interactions of PAL category with height and weight. The model performed to predict TEE used the following format:

TEE = Intercept + Age (years) + Height (cm) + Weight (kg) + PALCAT + PALCAT × Weight (kg) + PALCAT × Height (cm)

The full model output including all the coefficients for interaction terms of height and weight by PAL category are provided in Appendix G. For simplicity the TEE prediction equation is presented with slopes for height and weight separately for each PAL category in the following format:

TEE = Intercept + *A* × Age (years) + *B* × Height (cm) + *C* × Weight (kg)

In this equation *A*, *B*, and *C* are the model-based coefficients for the slopes of age, height, and weight, respectively, for each PAL category. Slopes for height and weight are allowed to vary by PAL category, whereas the slope for age did not vary across PAL categories.

A summary of TEE prediction equations for each age/sex group by PAL category is presented in Table 5-5. For boys and girls 0 to 2 years, TEE prediction equations were shown to differ by sex. Therefore, separate equations are presented for boys and girls. The sex-specific TEE prediction equations based on age, weight, and length/height are recommended for general use. Because of the limited range of physical activity in this youngest age group, TEE is not partitioned by PAL category.

Sex-specific TEE prediction equations using age, height, and weight for each PAL category are also shown by life-stage group in Table 5-5. See Appendix G for TEE prediction equations based only on weight (for children 0–2 years only) or body composition (FFM and FM).

For lactating women, TEE was not different from the nonpregnant, nonlactating state. Adjusted for current weight and PAL, TEE was not shown to be significantly different in lactating women (1–3 months postpartum, p = .311; 4–6 months postpartum, p = .811) compared to their nonpregnant, nonlactating state. Therefore, TEE prediction equations for women, 19+ years, or girls, 3 to 18 years, are recommended for lactating women and adolescents during the postpartum period.

Model Performance: Model Fit

The robustness of the TEE prediction equations was tested for all data within each strata and for subsets of data for each strata (all-included,

TABLE 5-5 TEE Prediction Equations by Age/Sex and Life-Stage Group

Men, 19 years and above	
Inactive	TEE = 753.07 – (10.83 × age) + (6.50 × height) + (14.10 × weight)
Low active	TEE = 581.47 – (10.83 × age) + (8.30 × height) + (14.94 × weight)
Active	TEE = 1,004.82 – (10.83 × age) + (6.52 × height) + (15.91 × weight)
Very active	TEE = – 517.88 – (10.83 × age) + (15.61 × height) + (19.11 × weight)
NOTE: R^2 = 0.73; R^2 adj = 0.73; R^2 shr = 0.73; RMSE = 339 kcal/d; MAPE = 9.4%; MAE = 266 kcal/d.	
Women, 19 years and above	
Inactive	TEE = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight)
Low active	TEE = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight)
Active	TEE = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight)
Very active	TEE = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight)
NOTE: R^2 = 0.71; R^2 adj = 0.70; R^2 shr = 0.70; RMSE = 246 kcal/d; MAPE = 8.7%; MAE = 191 kcal/d.	
Boys, 3–18 years	
Inactive	TEE = – 447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight)
Low active	TEE = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight)
Active	TEE = – 388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight)
Very active	TEE = – 671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight)
NOTE: R^2 = 0.92; R^2 adj = 0.92; R^2 shr = 0.92; RMSE = 259 kcal/d; MAPE = 7.1%; MAE = 163 kcal/d.	

Girls, 3–18 years

Inactive	TEE = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight)
Low active	TEE = – 297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight)
Active	TEE = – 189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight)
Very active	TEE = – 709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight)

NOTE: R^2 = 0.84; R^2 adj = 0.84; R^2 shr = 0.83; RMSE = 237 kcal/d; MAPE = 8.2%; MAE = 165 kcal/d.

Boys, 0–2 years

TEE = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight)

NOTE: R^2 = 0.83; R^2 adj = 0.83; R^2 shr = 0.83; RMSE = 104 kcal/d; MAPE = 13.6%; MAE = 79 kcal/d

Girls, 0–2 years

TEE = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight)

NOTE: R^2 = 0.83; R^2 adj = 0.83; R^2 shr = 0.83; RMSE = 95 kcal/d; MAPE = 12.8%; MAE = 74 kcal/d.

Pregnant women in their second and third trimester of pregnancy

Inactive	TEE = 1,131.20 – (2.04 × age) + (0.34 × height) + (12.15 × weight) + (9.16 × gestation)
Low active	TEE = 693.35 – (2.04 × age) + (5.73 × height) + (10.20 × weight) + (9.16 × gestation)
Active	TEE = –223.84 – (2.04 × age) + (13.23 × height) + (8.15 × weight) + (9.16 × gestation)
Very active	TEE = –779.72 – (2.04 × age) + (18.45 × height) + (8.73 × weight) + (9.16 × gestation)

NOTE: R^2 = 0.63; R^2 adj = 0.62; R^2 shr = 0.61; RMSE = 282 kcal/d; MAPE = 8.8%; MAE = 222 kcal/d.

NOTES: TEE = total energy expenditure; kcal/d = kilocalorie per day; TEE is in kilocalories/day, age is in years, weight is in kilograms, height is in centimeters, and gestation is in weeks. R^2 = R squared; R^2 adj = adjusted R squared; R^2 shr = shrunken R squared; RMSE = root mean squared error; MAPE = mean absolute percentage error; MAE = mean absolute error. RMSE is the same as standard error of the estimate (SEE).

sensitivity, normal weight BMI, overweight/obese BMI, FFM/FM), broken down by strata (men 19+ years, women 19+ years, boys 3–18 years, girls 3–19 years, boys 0–2 years, girls 0–2 years, and pregnant women). The summary statistics, including sample sizes, R^2, adjusted R^2, shrunken R^2, MSE, Pearson correlation r for predicted TEE versus observed TEE, MAPE, and MAE, are shown in Table 5-6 for the general TEE prediction equation based on weight and height/length and including all data within each strata. Performance of the other prediction equations are in Appendix G (and the supplemental appendixes).

The general TEE prediction models were compared against the other models based on the subsets of data for each strata (all-included versus sensitivity, normal BMI, overweight/obese BMI, FFM/FM). The first comparison evaluated the sensitivity of the general equation to extreme values observed in the underweight BMI and extreme obesity BMI categories. Elimination of participants with underweight or extreme obesity did not alter the performance of the general model, in terms of R^2, R^2 adj, r, MSE, or RMSE. (Implications of the prediction error on the application of the EER are discussed in Chapter 7.) Likewise, limiting the model to normal weight BMI only or overweight/obese BMI only did not significantly change these test statistics. Lastly, the prediction equation based on body composition (FFM and FM) performed slightly better than that based on weight in the adult model but not the child models.

TABLE 5-6 Evaluation of Model Fit for the General Total Energy Expenditure (TEE) Prediction Equations Based on Weight and Height/Length, by Strata

	Men	Women	Boys, 3–18 years	Girls, 3–18 years	Boys, 0–2 years	Girls, 0–2 years	Pregnancy
n	1,016	1,342	250	477	317	432	413
R^2	0.73	0.71	0.92	0.84	0.83	0.83	0.63
R^2 adj	0.73	0.70	0.92	0.84	0.83	0.83	0.62
R^2 shr	0.73	0.70	0.91	0.83	0.83	0.83	0.61
MSE (kcal/d)	114,615	60,393	66,831	56,049	10,733	9,059	79,770
RMSE (kcal/d)	339	246	259	237	104	95	282
MAPE (%)	9	9	7	8	14	13	9
MAE (kcal/d)	266	191	163	165	79	74	222

NOTES: R^2 = R squared; R^2 adj = adjusted R squared; R^2 shr = shrunken R squared; MSE = mean squared error; RMSE = root mean squared error; MAPE = mean absolute percentage error; MAE = mean absolute error. RMSE is the same as standard error of the estimate (SEE).

Model Performance by PAL Category, BMI Category, and Life Stage

The general TEE prediction equations were further tested by PAL category, BMI category, and life stage for each of the strata. In general, Pearson correlations (r) between predicted and observed values for PAL categories, BMI categories, and life stages ranged from ~0.75 to 0.95. Exceptions were seen for girls and boys, 0 to 2 years, where correlations were lower for 7- to 11-month-old and 1- to 3-year-old children compared with 0- to 6-month-old children, possibly owing to lower sample sizes in the former groups.

Model Comparisons: Normal BMI Compared to Overweight/Obese BMI

A major question for the committee was whether the general TEE prediction equation differed by BMI group, specifically for the normal weight versus overweight/obese BMI categories. In addition to the evaluations performed above, two-way and three-way interaction terms with BMI group were incorporated into the TEE prediction models. Differences in the slopes for height and weight were compared for each PAL category for adult men and women, boys and girls 3 to 18 years, and pregnant women. Importantly, none of the slopes were found to be significantly different at the $p = .05$ level.

Bland-Altman Plots

Bland-Altman plots of the predicted TEE versus observed TEE are displayed in Figure 5-5 for the general TEE prediction equations. On the x-axis is the mean of TEE observed and TEE predicted for each data point, and on the y-axis is the difference of TEE observed minus TEE predicted. Horizontal lines for the bias (i.e., the mean error) and the 95 percent limits of agreement (mean ±1.96 standard deviation) for the differences are also plotted. The mean and sample standard deviation for the difference between the observed and predicted TEE are shown in Table 5-7.

TABLE 5-7 Bias and Standard Deviation of the Differences Between the Observed Minus Predicted Values for TEE, by Strata

Strata	*n*	Bias (kcal/d)	Standard Deviation
Men, 19+ y	1,016	29.39	337
Women, 19+ y	1,342	0.61	246
Boys, 3–18 y	250	43.16	255
Girls, 3–18 y	477	11.45	237
Boys, 0–2 y	317	0.06	104
Girls, 0–2 y	432	0.51	95
Pregnant women	413	39.59	280

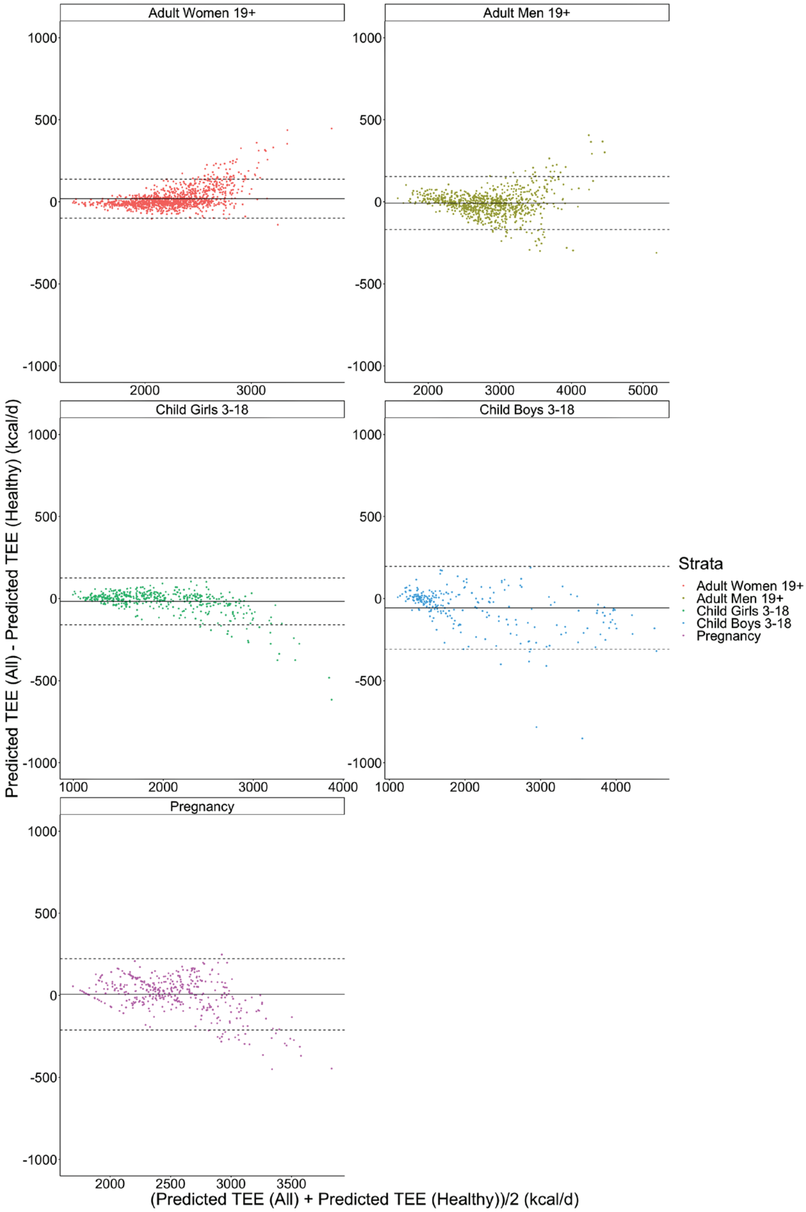

FIGURE 5-5 Bland-Altman plots of predicted TEE versus observed TEE (kcal/d) for the general TEE prediction equations. Solid lines represent the bias; dotted lines represent the 95% confidence interval around the bias (or bias ± 2 standard deviations).

Model Comparisons

The predicted TEE values from the five models (all-included, sensitivity, normal weight BMI, overweight/obese BMI, FFM/FM) were compared to inspect similarities or differences between how models fit on different subsets of participants based on BMI category. Pairwise comparisons for each pair of models were performed using Pearson *r* correlation of predicted TEE, the symmetric mean absolute percentage error (sMAPE), the MAE, MSE, and the RMSE. As expected, the predicted values from the five models were highly correlated. Results are shown in Appendix G.

Lastly, results from the different models can be visualized with plots showing TEE predictions for randomly selected people (see Supplemental Appendix R). About 100 people were randomly selected, with one from each combination of sex, age (life-stage group), BMI range, and PAL category. Their observed TEE data are shown in Panel 1, and their predicted TEE values from each of the five models are shown in the other panels. The predicted values can then be visually compared between models.

Prediction Error

The prediction errors for each of the TEE prediction equations are shown as the standard error (SE) of the predicted values for an individual at average levels of age, height, and weight, with an active PAL, within each stratum (Table 5-8). A 95 percent prediction interval can be calculated using the predicted value of TEE ±1.96 × SE, such that there is a 95 percent probability that an observation of TEE for a new person at the same levels of covariates will be contained within the prediction interval.

TABLE 5-8 Prediction Errors for the TEE Prediction Equations by Strata

Strata	Age (y)	Height (cm)	Weight (kg)	Weeks Pregnant	Predicted TEE (kcal/d)	SE of the Predicted Value (kcal/d)*
Men, 19+ years	50.3	175.9	83.1	—	2,930	342
Women, 19+ years	53.9	162.3	71.9	—	2,281	241
Boys, 0–2 years	0.7	68.5	8.0	—	624	104
Boys, 3–18 years	8.7	134.0	37.1	—	2,099	258
Girls, 0–2 years	0.7	68.3	7.8	—	593	96
Girls, 3–18 years	9.6	135.0	37.6	—	1,873	221
Pregnant	29.4	164.1	74.9	19.9	2,680	302

* Predicted values are reported as SE of the predicted values for each strata at average age, height, and weight. — No data are applicable in this category.

EXTERNAL MODEL VALIDATION

The committee, recognizing that the contents of the combined DLW database represent only a fraction of existing published data, determined to validate the TEE equations against existing published data for an out-of-sample model validation. A literature search was conducted to identify studies published between 2000 and 2022 that used DLW to measure TEE, contained the minimum necessary variables (i.e., sex and mean (standard deviation [SD]) age, height, weight, and TEE), and were not found in the combined DLW database (see Appendix D for details of the literature search). Using the same exclusion criteria applied to the combined DLW database, 65 studies were identified after full-text screening. These 65 studies comprised 144 age/sex-specific cohorts, representing 5,056 individual participants.

Only two studies with infant data were identified and dropped owing to the small sample size. Of the 144 cohorts, mean PAL values were presented for only 54 (38 percent). For cohorts without BMR or PAL values, estimated mean BMR was calculated using the age- and sex-specific Schofield equations and PAL was estimated accordingly. Details of the literature search, a summary of the DLW data extraction, and summary statistics for the included cohorts are found in Appendix I and Supplemental Appendix U.

The parameter estimates from the TEE equations developed on the combined DLW data set were used to calculate the "average participant's" TEE, based on sex, age, height, weight, and PAL category, for each validation cohort. The predicted value for each cohort was then compared to the observed TEE value using measures and assessed for model fit and performance. Two comparisons were made. First, predicted TEE was compared to observed TEE in those cohorts in which BMR and/or PAL were measured (n = 54) (Figure 5-6). The data points on Figure 5-6 are color-coded to represent the different PAL categories. As shown in Table 5-9, the model fits were very good across all sex-age groups, according to the selected model performances.

The second comparison used all validation study data, including observed and imputed PAL (144 cohorts) (Figure 5-7). As with observed PAL, the model fit was very good across all age/sex groups (Table 5-10).

ENERGY COSTS OF GROWTH, PREGNANCY, AND LACTATION

Growth of Infants, Children, and Adolescents

The energy requirements of infants, children, and adolescents includes the energy required for deposition of tissues consistent with health. Humans' relatively slow growth rates as a species mean that the energy

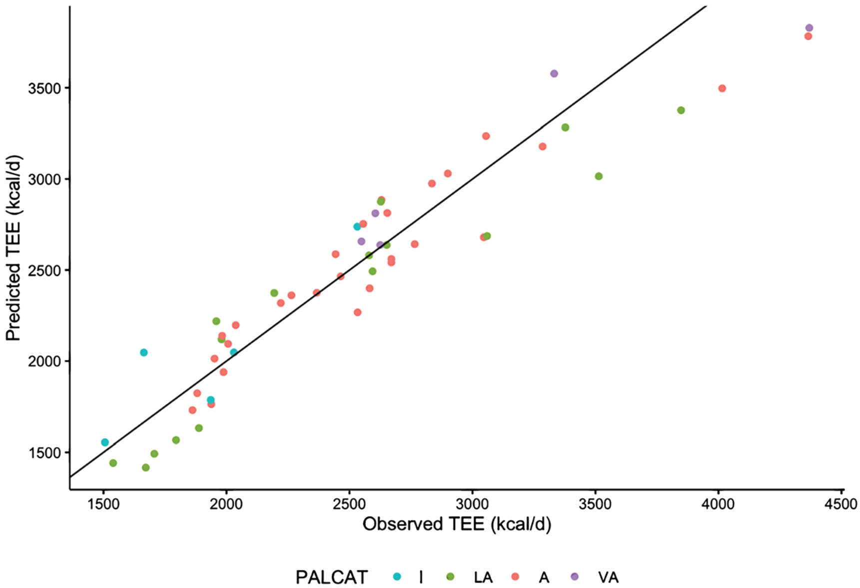

FIGURE 5-6 For external validation of the TEE prediction equations, predicted TEE is plotted against observed TEE in those studies in which BMR and/or PAL were measured (*n* = 54).
NOTE: A = active; LA = low active; I = inactive; VA = very active; TEE = total energy expenditure; PALCAT = physical activity level category.

TABLE 5-9 Evaluation of Model Fit for the TEE Prediction Equations Compared to External Validation Studies with Observed PAL Values (*n* = 54 cohorts)

	Number of cohorts	R^2	R	MSE	RMSE (kcal/d)	MAPE (%)
Boy	8	0.90	0.96	95,651	309	7.90
Girl	7	0.82	0.97	56,812	238	10.38
Man	14	0.85	0.93	45,699	213	6.00
Woman	25	0.85	0.94	44,940.87	212	6.83

NOTES: R^2 = R squared; R = correlation; MSE = mean squared error; RMSE = root mean squared error; MAPE = mean absolute percentage error.

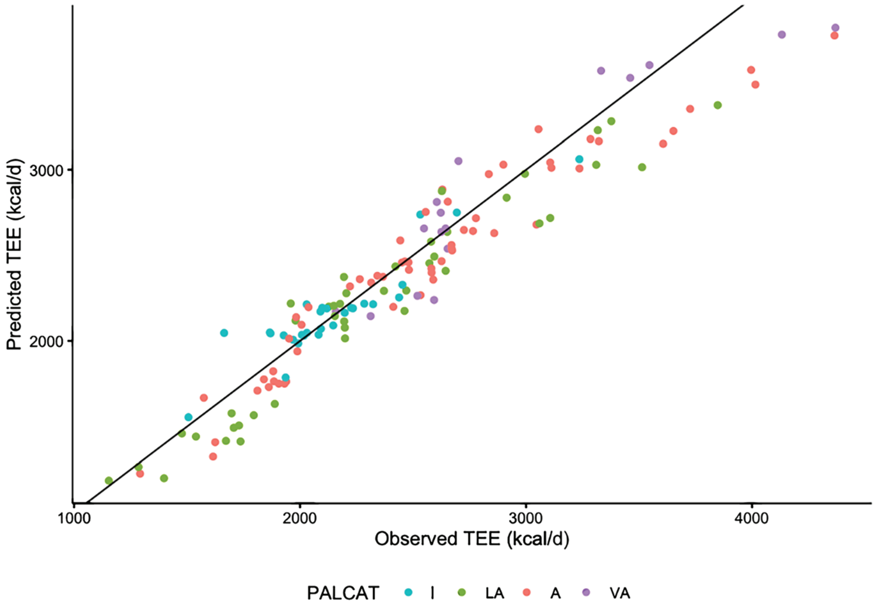

FIGURE 5-7 For external validation of the TEE prediction equations, predicted TEE is plotted against observed TEE in studies with observed and imputed PAL values (n = 144).
NOTES: A = active; LA = low active; I = inactive; VA = very active; TEE = total energy expenditure; PALCAT = physical activity level category.

TABLE 5-10 Evaluation of Model Fit for the TEE Prediction Equations Compared to External Validation Studies with Observed PAL Values (n = 144 cohorts)

	Number of Cohorts	R^2	R	MSE	RMSE (kcal/d)	MAPE (%)
Boy	21	0.92	0.96	61,755	248	7.72
Girl	20	0.87	0.97	35,342	188	8.01
Man	32	0.82	0.92	49,684	222	5.57
Woman	71	0.82	0.93	28,833	169	5.46

NOTE: R^2 = R squared; R = correlation; MSE = mean squared error; RMSE = root mean squared error; MAPE = mean absolute percentage error.

requirements for growth relative to maintenance are small, except during the first months of life. To estimate the energy cost of growth, one must estimate weight velocity and the energy content of the newly synthesized tissues, preferably from the separate costs of protein and fat deposition. The committee estimated the energy cost of growth for children 0 to 2 years from the energy cost of tissue deposition based on protein and fat accretion (Butte, 2005; Butte et al., 2000a,b) and WHO weight velocities[4] rounded to 5-kcal increments, grouping 0 to 2.99 months, 3 to 5.99 months, 6 to 11.99 months, and 12 to 24 months (Table 5-11). For boys, the energy cost of growth is approximately 200 kcal/d for 0 to 2.99 months, 50 kcal/d for 3 to 5.99 months, and 20 kcal/d for 6 to 24 months of age. For girls, the energy cost of growth is approximately 180 kcal/d for 0 to 2.99 months, 60 kcal/d for 3 to 5.99 months, 20 kcal/d for 6 to 11 months, and 15 kcal/d for 12 to 24 months of age.

Data for the energy cost of growth from 24 to 35 months were lacking for both sexes, and thus the committee recommended extending the additional calories from the previous time frame, 20 kcal/d for boys and 15 kcal/d for girls.

The energy costs of growth for children 3–18 years were estimated based on rates of weight gain of children enrolled in the Fels Longitudinal Study (Baumgartner et al., 1986) (Table 5-12). Body composition increments were used to estimate the energy cost of tissue deposition (Fomon et al., 1982; Haschke, 1989). The energy cost of growth was about 15 kcal/d in children 4 to 8 years, 25 kcal/d in boys 9 to 13 years, 30 kcal/d in girls 9 to 13 years, and 20 kcal/d in children 14 to 18 years. Data for 3-year-olds were estimated by averaging the values for 12- to 24-month-olds and 3- to 3.5-year-olds from the Fels study, resulting in values that were consistent with the 1- to 3-year-olds, 20 kcal/d for boys and 15 kcal/d for girls.

Energy Cost of Tissue Accretion During Pregnancy

Guidelines for weight gain during pregnancy stipulate a range of weight gain, based on prepregnancy BMI, that will optimize both maternal and fetal outcomes (IOM and NRC, 2009). Consistent with this premise, the committee determined that the energy cost of tissue accretion during the second and third trimesters of pregnancy should be based on body composition changes in women who gained within the IOM weight gain guidelines for their prepregnancy BMI category (IOM and NRC, 2009). Weight gain in the first trimester is minor and therefore not considered here.

[4] https://www.who.int/tools/child-growth-standards/standards/weight-velocity (accessed November 14, 2022).

TABLE 5-11 Energy Cost of Growth, Infants, and Children Aged 0–2 Years

	Age Range (months)	WHO Weight Velocity (g/d)[a]	Cost of Tissue Deposition (kcal/g)[b]	Energy Deposition (kcal/d)[c]
Boys	0–2.99	32.77	6.0	196.6
	3–5.99	17.35	2.8	48.6
	6–8.99	10.55	1.5	15.8
	9–11.99	8.09	2.7	21.8
	12–14.99	7.03	2.2	15.5
	15–17.99	6.6	2.2	14.5
	18–20.99	6.43	4.7	30.2
	21–24	6.11	4.7	28.7
Girls	0–2.99	28.55	6.3	179.9
	3–5.99	16.21	3.7	60.0
	6–8.99	10.14	1.8	18.3
	9–11.99	7.74	2.3	17.8
	12–14.99	7.04	2.5	17.6
	15–17.99	6.9	2.5	17.3
	18–20.99	6.68	2.2	14.7
	21–24	6.26	2.2	13.8

NOTE: d = day; g = grams; kcal = kilocalorie; WHO = World Health Organization.
[a] Weight velocity (https://www.who.int/tools/child-growth-standards/standards/weight-velocity (accessed November 14, 2022).
[b] Body composition increments used to estimate energy costs of tissue deposition (kcal/g) (Butte, 2005; Butte et al., 2000a,b).
[c] Energy deposition (kcal/d) estimated by applying energy costs of tissue deposition (kcal/g) to WHO weight velocities (g/d).

The committee found only three studies that differentiated weight gain by IOM guidelines (IOM and NRC, 2009), which it used in estimating these costs (Butte et al., 2004; Lederman et al., 1997; Most et al., 2019). Combined sample sizes were 11 women with underweight, 66 with normal weight, 19 with overweight, and 14 with obesity. Across BMI categories, approximately 7 g/d of protein was deposited in fetal and maternal tissues. In contrast, fat mass deposition was variable within and across BMI categories. In underweight, normal weight, and overweight BMI categories, FM deposition averaged about 35 g/d, whereas in the obese BMI category, FM was mobilized (approximately –10 g/d). These body composition changes were used to calculate the energy cost of tissue deposition per gram gained (Table 5-13). These energy costs of tissue deposition per gram gained were then multiplied by the IOM recommendations for gestational weight gain (GWG).

TABLE 5-12 Energy Cost of Growth in Children, Aged 3–18 Years

	Age at End of Interval (y)	Weight Gain (kg/6 month)[a]	Weight Gain (g/d)[a]	Energy Cost of Tissue Deposition (kcal/g)[b]	Energy Deposition (kcal/d)[c]
Boys	3.5	1	5.5	1.5	8.2
	4.5	1.1	6.0	1.5	9.0
	5.5	1.2	6.6	1.5	9.9
	6.5	1.2	6.6	1.7	11.1
	7.5	1.4	7.7	2.4	18.4
	8.5	1.4	7.7	2.4	18.4
	9.5	1.5	8.2	2.6	21.3
	10.5	1.6	8.7	2.9	25.4
	11.5	1.9	10.4	3.1	32.2
	12.5	2.5	13.7	1.8	24.6
	13.5	3.1	16.9	1.3	22.0
	14.5	3.7	20.2	1.5	30.3
	15.5	2.6	14.2	1.7	24.2
	16.5	1.7	9.3	1.9	17.7
	17.5	1.1	6.0	2	12.0
Girls	3.5	1	5.5	1.7	9.3
	4.5	0.9	4.9	2	9.8
	5.5	1	5.5	2.2	12.0
	6.5	1.2	6.6	2.6	17.0
	7.5	1.3	7.1	2.9	20.6
	8.5	1.5	8.2	3.1	25.4
	9.5	1.5	8.2	3.3	27.0
	10.5	2	10.9	2.8	30.6
	11.5	2.5	13.7	2.3	31.4
	12.5	2.8	15.3	1.9	29.1
	13.5	2.3	12.6	3	37.7
	14.5	1.5	8.2	4.1	33.6
	15.5	0.9	4.9	5.1	25.1
	16.5	0.8	4.4	4.9	21.4
	17.5	0.4	2.2	4	8.7

NOTE: d = day; g = grams; kcal = kilocalorie; kg = kilogram; y = years.

[a] Increments in weight 50th percentile (Baumgartner et al., 1986).

[b] Body composition increments used to estimate energy cost of tissue deposition (Fomon et al., 1982; Haschke, 1989).

[c] Energy deposition (kcal/d) estimated by applying energy cost of tissue deposition (kcal/g) to Baumgartner et al. (1986) rates of weight gain (g/d).

TABLE 5-13 Energy Cost of Tissue Deposition in Pregnancy Based on Recommended Rates of Weight Gain[a]

Prepregnancy BMI	Recommended rates of GWG in 2nd and 3rd trimesters (kg/wk)[a]	Recommended rates of GWG in 2nd and 3rd trimesters (g/d)[a]	Energy cost of tissue deposition per gram gained, weighted for sample size (kcal/g)[b]	Energy cost of tissue deposition (kcal/d)	Energy cost of tissue deposition, rounded (kcal/d)
Underweight	0.51	72.86	4.08	297.18	300
Normal weight	0.42	60.00	3.41	204.46	200
Overweight	0.28	40.00	3.80	152.02	150
Obese	0.22	31.43	–2.06	–64.63	–50

NOTE: d = day; g = grams; GWG = gestational weight gain; kcal = kilocalorie; kg = kilogram; wk = week.

[a] Recommended rates of gestational weight gain are from the Institute of Medicine guidelines (IOM and NRC, 2009).

[b] Energy cost of tissue deposition based on longitudinal changes in body composition; calculated using energy equivalences of 5.65 kcal/g protein and 9.25 kcal/g fat (Butte et al., 2004; Lederman et al., 1997; Most et al., 2019).

For women with underweight, the IOM recommended rate of GWG is 73 g/d in the second and third trimesters, which translates to approximately 300 kcal/d (IOM and NRC, 2009). For women with normal weight, the IOM recommended rate of GWG is 60 g/d in the second and third trimesters, which translates to approximately 200 kcal/d (IOM and NRC, 2009). For women with overweight, the IOM recommended rate of GWG is 40 g/d, which translates to approximately 150 kcal/d (IOM and NRC, 2009). For women with obesity, the IOM recommended rate of GWG is 31 g/d, which translates to approximately –50 kcal/d (IOM and NRC, 2009). Mobilization of tissue such as fat is considered negative energy cost.

Energy Cost of Milk Production

The American Academy of Pediatrics, the Canadian Pediatric Society, and WHO recommend exclusive breastfeeding for about 6 months, with complementary foods introduced around 6 months, and continued breastfeeding until 2 years or beyond, as mutually desired by mother and child (Critch et al., 2013, 2014; Meek et al., 2022; WHO, 2021). In this report, the energy cost of milk production was based on rates of human milk production in exclusively breastfeeding women in the first 6 months postpartum (Allen et al., 1991; Butte et al., 1984a; Reilly et al., 2005), and in partially breastfeeding women in the second 6 months

TABLE 5-14 Energy Cost of Milk Production in Breastfeeding Women During the First Year Postpartum

	Time Postpartum				
	0–2 months	3–4 months	5 months	6 months	7–12 months
Human milk production (g/d) [a,b]	732[a]	779 [b]	826 [b]	894[b]	568[c]
Gross energy content (kcal/g)[b]	0.67	0.67	0.67	0.67	0.67
Total cost of milk production (kcal/d)	490	522	553	599	381
Maternal weight loss (kcal/d)[d]	–137	–137	–137	–137	NA
Net energy cost of milk production (kcal/d)	353	385	416	462	381

NOTE: d = day; g = grams; kcal = kilocalorie.

[a] Exclusively breastfeeding women (Allen et al., 1991; Butte et al., 1984a).

[b] Exclusively breastfeeding women (Reilly et al., 2005).

[c] Partially breastfeeding women (Dewey et al., 1984; Heinig et al., 1993; Pereira et al., 2019).

[d] Mean weight loss (0.64 kg/mo) and energy content of tissues mobilized (6,500 kcal/kg) based on 2,393 longitudinal studies: (Brewer et al., 1989; Butte et al., 1984b, 2001; Dewey et al., 1993; Goldberg et al., 1991; Manning-Dalton and Allen, 1983; Naismith and Ritchie, 1975; Sadurskis et al., 1988; Sohlstrom and Forsum, 1995; van Raaij et al., 1991; Wosje and Kalkwarf, 2004).

postpartum (Dewey et al., 1984; Heinig et al., 1993; Pereira et al., 2019) (see Table 5-14). The gross energy content of milk was derived from bomb calorimetry or proximate macronutrient analysis, averaging 0.67 kcal/g (Reilly et al., 2005). The total cost of milk production may be subsidized by mobilization of tissue reserves in the postpartum period. During the first 6 months postpartum, breastfeeding women had a gradual weight loss averaging 0.64 kg/month (Brewer et al., 1989; Butte et al., 1984b, 2001; Dewey et al., 1993; Goldberg et al., 1991; Manning-Dalton and Allen, 1983; Naismith and Ritchie, 1975; Sadurskis et al., 1988; Sohlstrom and Forsum, 1995; van Raaij et al., 1991; Wosje and Kalkwarf, 2004).

From 0 to 6 months postpartum, the net energy cost of milk production averages 404 kcal/d to support an average milk volume of 808 g/d in exclusively breastfeeding women experiencing gradual weight loss (0.64 kg/month). In the second 6 months postpartum, weight changes are variable depending on the amount of milk produced, complementary feeding, maternal food intake, and physical activity. If weight is stable, an extra 380 kcal/d are required to support milk production at a level of 570 g/d. In the second year of lactation, the energy cost of milk production is variable, depending on child demand and maternal factors.

ESTIMATED ENERGY REQUIREMENTS

Boys and Girls, 0 to 2.99 Years

The EER for young children are based on an allowance for growth in addition to TEE (Table 5-15). For boys and girls, 0 to 2.99 years, the sex-specific TEE prediction equations based on age, weight, and height are recommended for general use. See Appendix G for TEE prediction equations based on weight only or on body composition (FFM and FM). For boys, the energy cost of growth is estimated to be 200 kcal/d for 0 to 3 months, 50 kcal/d for 3 to 6 months, and 20 kcal/d for 6 to 35.99 months of age. For girls, the energy cost of growth is estimated to be 180 kcal/d for 0 to 3 months, 60 kcal/d for 3 to 6 months, 20 kcal/d for 6 to 11 months, and 15 kcal/d for 12 to 35.99 months of age. Therefore, the EER for boys and girls is the sum of TEE and the age- and sex-specific energy cost of growth.

Boys and Girls, 3 to 18.99 Years

The EER for children 3 to 18.99 years is based on sex-specific TEE prediction equations using age, height, and weight for each PAL category (Table 5-15). Importantly, the general TEE prediction equations are recommended for all BMI categories, as testing of separate prediction equations did not show significant differences by BMI category at the $p = .05$ level. See Appendix G for TEE prediction equations based on body composition (FFM and FM). The energy cost of growth from 24 to 35 months was set at 20 kcal/d for boys and 15 kcal/d for girls; these same values were also set for 3-year-olds. The energy cost of growth was about 15 kcal/d in children 4 to 8 years, 25 kcal/d in boys 9 to 13 years, 30 kcal/d in girls 9 to 13 years, and 20 kcal/d in boys and girls 14 to 18 years. Therefore, the EER for boys and girls 3 to 18.99 years is the sum of TEE and the age-specific energy cost of growth.

Men and Women, 19 Years and Above

The EER for adults, 19 years and above, is based on sex-specific TEE prediction equations using age, height, and weight for each PAL category (Table 5-16). Importantly, the general TEE prediction equations are recommended for all BMI categories, as testing of separate prediction equations did not show significant differences by BMI category at the $p = .05$ level. TEE prediction equations based on body composition (FFM and FM) are available in Appendix G. In weight-stable men and women, TEE represents their EER.

TABLE 5-15 Summary Table of EER Equations by Age, Sex, Physical Activity, and Energy Cost of Growth: Children and Adolescents

Age Group	Sex	PAL Category	EER Equation (kcal/d)
0–2.99 months	M	–	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 200
	F	–	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 180
3–5.99 months	M	–	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 50
	F	–	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 60
6 months–2.99 years	M	–	EER = –716.45 – (1.00 × age) + (17.82 × height) + (15.06 × weight) + 20
	F	–	EER = –69.15 + (80.0 × age) + (2.65 × height) + (54.15 × weight) + 20/15[a]
3–13.99 years	M	Inactive	EER = –447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight) + 20/15/25[b]
		Low active	EER = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight) + 20/15/25
		Active	EER = –388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight) + 20/15/25
		Very active	EER = –671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight) + 20/15/25
	F	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + 15/30[c]
		Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + 15/30
		Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + 15/30
		Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + 15/30
14–18.99 years	M	Inactive	EER = –447.51 + (3.68 × age) + (13.01 × height) + (13.15 × weight) + 20
		Low active	EER = 19.12 + (3.68 × age) + (8.62 × height) + (20.28 × weight) + 20
		Active	EER = –388.19 + (3.68 × age) + (12.66 × height) + (20.46 × weight) + 20
		Very active	EER = –671.75 + (3.68 × age) + (15.38 × height) + (23.25 × weight) + 20
	F	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + 20

continued

TABLE 5-15 Continued

Age Group	Sex	PAL Category	EER Equation (kcal/d)
		Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + 20
		Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + 20
		Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + 20

NOTES: kcal/d = kilocalories per day; PAL = physical activity level; EER = Estimated Energy Requirement. Age is in years, weight is in kilograms, and height is in centimeters.

[a] Energy cost of growth for girls: 6–11.99 months: 20 kcal/d; 12–35.99 months: 15 kcal/d.

[b] Energy cost of growth for boys: 3 y: 20 kcal/d; 4 to 8 y: 15 kcal/d; 9 to 13 y: 25 kcal/d.

[c] Energy cost of growth for girls: 3 y: 15 kcal/d; 4 to 8 y: 15 kcal/d; 9 to 13 y: 30 kcal/d.

TABLE 5-16 Summary Table of EER Equations Based on the TEE Prediction by Age, Sex, and Physical Activity: Adults

Age Group	Sex	PAL Category	EER Equation (kcal/d)
19+ years	M	Inactive	EER = 753.07 – (10.83 × age) + (6.50 × height) + (14.10 × weight)
		Low active	EER = 581.47 – (10.83 × age) + (8.30 × height) + (14.94 × weight)
		Active	EER = 1,004.82 – (10.83 × age) + (6.52 × height) + (15.91 × weight)
		Very active	EER = –517.88 – (10.83 × age) + (15.61 × height) + (19.11 × weight)
	F	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight)
		Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight)
		Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight)
		Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight)

NOTES: kcal/d = kilocalories per day; PAL = physical activity level; EER = Estimated Energy Requirement; TEE = total energy expenditure. For weight stable adults, EER (kcal/d) = TEE (kcal/d). Age is in years, weight is in kilograms, and height is in centimeters.

Pregnancy

The EER for pregnant women during the second and third trimesters is based on the TEE prediction equations using age, height, current weight, and gestational weeks for each PAL category, plus the energy deposition in maternal and fetal tissues (Table 5-17). Importantly, the general TEE prediction equations are recommended for all BMI categories, as testing of separate prediction equations did not show significant differences by BMI category at the p = .05 level. Because of the paucity of data on pregnant adolescents, the EERs derived from adults are recommended for this age group. See Appendix G for TEE prediction equations based on body composition (FFM and FM).

The EER for the first trimester of pregnancy should be estimated from the nonpregnant TEE prediction equations. Because weight gain is minor and variable in the first trimester, no allowance is made for energy deposition. Energy deposition is based on the IOM recommended GWG for the second and third trimesters. For underweight women, the IOM recommended rate of GWG is 73 g/d in the second and third trimesters, which translates to an energy deposition of approximately 300 kcal/d. For normal weight women, the IOM and NRC (2009) recommended rate of GWG is 60 g/d in the second and third trimesters, which translates to an energy deposition of approximately 200 kcal/d. For women with overweight, the IOM recommended rate of GWG is 40 g/d, which translates to an energy deposition of approximately 150 kcal/d. For women with obesity, the IOM and NRC (2009) recommended rate of GWG is 31 g/d, which translates to an energy mobilization of approximately –50 kcal/d. The EER for pregnant women is thus calculated as the sum of TEE and energy deposition/mobilization.

TABLE 5-17 Summary Table of EER Equations for Pregnant Women During the Second and Third Trimesters of Pregnancy

Life Stage	PAL Category	EER Equation (kcal/day)
2nd and 3rd trimester of pregnancy[a]	Inactive	EER = 1,131.20 – (2.04 × age) + (0.34 × height) + (12.15 × weight) + (9.16 × gestation) + energy deposition
	Low active	EER = 693.35 – (2.04 × age) + (5.73 × height) + (10.20 × weight) + (9.16 × gestation) + energy deposition
	Active	EER = –223.84 – (2.04 × age) + (13.23 × height) + (8.15 × weight) + (9.16 × gestation) + energy deposition
	Very active	EER = –779.72 – (2.04 × age) + (18.45 × height) + (8.73 × weight) + (9.16 × gestation) + energy deposition

NOTES: For pregnancy: EER (kcal/d) = TEE (kcal/d) + energy deposition (kcal/d). Energy deposition/mobilization (kcal/d) estimated for underweight (UW), normal weight (NW), overweight (OW), and obese (OB) pregnant women during the 2nd and 3rd trimesters of pregnancy: + 300 kcal/d for UW; + 200 kcal/d for NW; + 150 kcal/d for OW; –50 kcal/d for OB. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, gestation is in weeks, energy deposition is in kilocalories/day.

[a] For the 1st trimester of pregnancy, the nonpregnant TEE prediction equation should be used. It is assumed that energy deposition/mobilization is negligible and therefore ignored.

Lactation

The EERs for lactating women are based on rates of TEE, milk energy output, and energy mobilization from stores (Tables 5-18 and 5-19). Because TEE adjusted for weight and PAL were not shown to be significantly different in lactating women compared to their nonpregnant and nonlactating state, the TEE prediction equations for women, 19 years and above, are recommended. For lactating adolescents, less than 19 years, the TEE prediction equations for girls 14 to 18.99 years are recommended. See Appendix G for TEE prediction equations based on body composition (FFM and FM). Weight stability is assumed after 6 months postpartum.

TABLE 5-18 Summary Table of EER Equations for Women and Girls Exclusively Breastfeeding 0 to 6 Months Postpartum

Age Group	PAL Category	EER Equation (kcal/day)
Women, 19 years and above	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight) + energy cost of milk production – energy mobilization
	Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight) + energy cost of milk production – energy mobilization
	Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight) + energy cost of milk production – energy mobilization
	Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight) + energy cost of milk production – energy mobilization
Girls, < 19 years	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + energy cost of milk production – energy mobilization
	Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + energy cost of milk production – energy mobilization
	Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + energy cost of milk production – energy mobilization
	Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + energy cost of milk production – energy mobilization

NOTES: For exclusively breastfeeding 0–6 months postpartum: EER (kcal/d) = TEE (kcal/d) + energy cost of milk production (kcal/d) – energy mobilization (kcal/d). Energy cost of milk production estimated for women and girls exclusively breastfeeding 0–6 months postpartum: 540 kcal/d. Energy mobilization estimated for women and girls exclusively breastfeeding 0 to 6 months postpartum: 140 kcal/d. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, energy cost of milk production is in kilocalories/day, and energy mobilization is in kilocalories/day.

TABLE 5-19 Summary Table of EER Equations for Women and Girls Partially Breastfeeding 7 to 12 Months Postpartum

Age Group	PAL Category	EER Equation (kcal/day)
Women, 19 years and above	Inactive	EER = 584.90 – (7.01 × age) + (5.72 × height) + (11.71 × weight) + energy cost of milk production
	Low active	EER = 575.77 – (7.01 × age) + (6.60 × height) + (12.14 × weight) + energy cost of milk production
	Active	EER = 710.25 – (7.01 × age) + (6.54 × height) + (12.34 × weight) + energy cost of milk production
	Very active	EER = 511.83 – (7.01 × age) + (9.07 × height) + (12.56 × weight) + energy cost of milk production
Girls, < 19 years	Inactive	EER = 55.59 – (22.25 × age) + (8.43 × height) + (17.07 × weight) + energy cost of milk production
	Low active	EER = –297.54 – (22.25 × age) + (12.77 × height) + (14.73 × weight) + energy cost of milk production
	Active	EER = –189.55 – (22.25 × age) + (11.74 × height) + (18.34 × weight) + energy cost of milk production
	Very active	EER = –709.59 – (22.25 × age) + (18.22 × height) + (14.25 × weight) + energy cost of milk production

NOTES: For partially breastfeeding 7–12 months postpartum: EER (kcal/d) = TEE (kcal/d) + energy cost of milk production (kcal/d). Energy cost of milk production estimated for women and girls partially breastfeeding 7–12 months postpartum: 380 kcal/d. EERs are in kilocalories/day, age is in years, height is in centimeters, weight is in kilograms, and energy cost of milk production is in kilocalories/day.

FINDINGS AND CONCLUSIONS

Findings

Based on its analysis of the assembled DLW database of 8,600 values representing infants, children, adolescents, adults, and reproductive age women, the committee finds that TEE and PAL changed in a curvilinear fashion across the life span, which influenced development of the TEE prediction equations. Specifically, the committee found that sex differences in TEE were observed across the life span.

Testing of separate TEE prediction equations for normal weight BMI compared to the overweight/obese BMI did not reveal statistically significant differences. Similarly, the committee finds that TEE prediction equations for pregnant women in the second and third trimesters of pregnancy did not differ significantly between women with normal weight BMI and those with overweight/obese BMI. When TEE was adjusted for weight and PAL, there was no statistically significant difference among lactating women compared to their nonpregnant state. The committee also found that its calculated EER equations were consistent with the IOM and NRC (2009) weight gain guidelines, and with the TEE plus the energy cost of milk production during lactation.

The committee finds that alternative TEE prediction equations developed based on height and body composition (FFM and FM) performed slightly better than those based on weight and height for adults, but not for children. Pearson correlations (r) between predicted and observed values for PAL categories, BMI categories, and life stages ranged from approximately 0.75 to 0.95. The standard error (SE) of the predicted values for people at average levels of age, height, and weight within each strata ranged from 96 to 342 kcal/d. In an external validation of the TEE prediction equation based on 65 studies representing 5,056 participants, the Pearson correlations (r) between predicted and observed TEE (n = 144) ranged from 0.92 to 0.97.

Conclusions

From its analysis of representative DLW values across the life span, the committee concludes that in order to address the age-dependent curvilinearity of TEE, sex-specific TEE prediction equations were needed for children, 0 to 2 years and 3 to 18 years, and adults, 19 years and above. Additionally, age-specific coefficients for PAL categories defined as inactive, low active, active, and very active were incorporated into the TEE prediction equations to address the age dependency of PAL. However, because of the limited range of physical activity in children 0 to 2 years old, TEE could not be partitioned by PAL category.

Based on the testing of TEE equations in normal and overweight/obese BMI categories, the committee concludes that the same TEE prediction equations are recommended for infants, children, and adults, regardless of BMI classification. Further, the TEE prediction equations are also recommended for all pregnant women, regardless of BMI classification, and the TEE of lactating women and adolescents may be predicted from nonpregnant TEE equations.

From its findings on the TEE prediction equations based on height and body composition, the committee concludes that TEE prediction equations based on height and body composition are marginally better than those based on weight and height in adults, and may be used where body composition data are available. Additionally, the committee concludes that correlations between predicted and observed values for TEE are moderate to high across

PAL categories, BMI categories, and life stages; standard errors of the predicted values ranging from 96 to 342 kcal/d depending on sex-age strata indicated a level of uncertainty in predicting an individual's TEE.

The committee concludes from its external validation of the new TEE prediction equations that close agreement between the observed mean TEE in studies and predicted means confirmed the robustness of the prediction equations.

Overall, the committee concludes that its calculated EER equations were based upon TEE in weight stable adults, and on TEE plus the energy cost of growth in children, on TEE plus the energy cost of tissue accretion during the second and third trimesters of pregnancy consistent with the IOM and NRC (2009) weight gain guidelines, and TEE plus the energy cost of milk production during lactation.

REFERENCES

Allen, J. C., R. P. Keller, P. Archer, and M. C. Neville. 1991. Studies in human lactation: Milk composition and daily secretion rates of macronutrients in the first year of lactation. *American Journal of Clinical Nutrition* 54(1):69-80.

Baumgartner, R. N., A. F. Roche, and J. H. Himes. 1986. Incremental growth tables: Supplementary to previously published charts. *American Journal of Clinical Nutrition* 43(5):711-722.

Black, A. E., A. M. Prentice, and W. A. Coward. 1986. Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure. *Human Nutrition: Clinical Nutrition* 40(5):381-391.

Black, A. E., W. A. Coward, T. J. Cole, and A. M. Prentice. 1996. Human energy expenditure in affluent societies: An analysis of 574 doubly-labelled water measurements. *European Journal of Clinical Nutrition* 50(2):72-92.

Brewer, M. M., M. R. Bates, and L. P. Vannoy. 1989. Postpartum changes in maternal weight and body fat depots in lactating vs nonlactating women. *American Journal of Clinical Nutrition* 49(2):259-265.

Butte, N. F. 2005. Energy requirements of infants. *Public Health Nutrition* 8(7A):953-967.

Butte, N. F., and B. Caballero. 2014. Energy needs: Assessment and requirements. In *Modern nutrition in health and disease.* 11th ed., edited by A. C. Ross, B. Caballero, R. J. Cousins, K. L. Tucker and T. R. Ziegler. Baltimore, MD: Lippincott, Williams and Wilkins.

Butte, N. F., C. Garza, E. O. Smith, and B. L. Nichols. 1984a. Human milk intake and growth in exclusively breast-fed infants. *Journal of Pediatrics* 104(2):187-195.

Butte, N. F., C. Garza, J. E. Stuff, E. O. Smith, and B. L. Nichols. 1984b. Effect of maternal diet and body composition on lactational performance. *American Journal of Clinical Nutrition* 39(2):296-306.

Butte, N. F., J. M. Hopkinson, W. W. Wong, E. O. Smith, and K. J. Ellis. 2000a. Body composition during the first 2 years of life: An updated reference. *Pediatric Research* 47(5):578-585.

Butte, N. F., W. W. Wong, J. M. Hopkinson, C. J. Heinz, N. R. Mehta, and E. O. Smith. 2000b. Energy requirements derived from total energy expenditure and energy deposition during the first 2 y of life. *American Journal of Clinical Nutrition* 72(6):1558-1569.

Butte, N. F., W. W. Wong, and J. M. Hopkinson. 2001. Energy requirements of lactating women derived from doubly labeled water and milk energy output. *Journal of Nutrition* 131(1):53-58.

Butte, N. F., W. W. Wong, M. S. Treuth, K. J. Ellis, and E. O'Brian Smith. 2004. Energy requirements during pregnancy based on total energy expenditure and energy deposition. *American Journal of Clinical Nutrition* 79(6):1078-1087.

CDC (Centers for Disease Control and Prevention). 2009. *Percentile data files with LMS values*. https://www.cdc.gov/growthcharts/percentile_data_files.htm (accessed November 28, 2022).

Critch, J. N., Canadian Paediatric Society, Nutrition and Gastroenterology Committee. 2013. Nutrition for healthy term infants, birth to six months: An overview. *Paediatrics & Child Health* 18(4):206-209.

Critch, J. N., Canadian Paediatric Society, Nutrition and Gastroenterology Committee. 2014. Nutrition for healthy term infants, six to 24 months: An overview. *Paediatrics & Child Health* 19(10):547-552.

Dewey, K. G., D. A. Finley, and B. Lonnerdal. 1984. Breast milk volume and composition during late lactation (7-20 months). *Journal of Pediatric Gastroenterology and Nutrition* 3(5):713-720.

Dewey, K. G., M. J. Heinig, and L. A. Nommsen. 1993. Maternal weight-loss patterns during prolonged lactation. *American Journal of Clinical Nutrition* 58(2):162-166.

FAO (Food and Agriculture Organization of the United Nations). 2004. Human energy requirements: Report of a joint FAO/WHO/UNU expert consultation. https://www.fao.org/3/y5686e/y5686e00.htm (accessed November 11, 2022).

Fomon, S. J., F. Haschke, E. E. Ziegler, and S. E. Nelson. 1982. Body composition of reference children from birth to age 10 years. *American Journal of Clinical Nutrition* 35(5 Suppl):1169-1175.

Goldberg, G. R., A. M. Prentice, W. A. Coward, H. L. Davies, P. R. Murgatroyd, M. B. Sawyer, J. Ashford, and A. E. Black. 1991. Longitudinal assessment of the components of energy balance in well-nourished lactating women. *American Journal of Clinical Nutrition* 54(5):788-798.

Haschke, F. 1989. Body composition during adolescence. In *Body composition measurements in infants and children: Report of the 98th Ross conferences on pediatric research*. Columbus, OH: Ross Laboratories. Pp. 76-83.

Heinig, M. J., L. A. Nommsen, J. M. Peerson, B. Lonnerdal, and K. G. Dewey. 1993. Intake and growth of breast-fed and formula-fed infants in relation to the timing of introduction of complementary foods: The darling study. Davis area research on lactation, infant nutrition and growth. *Acta Paediatrica* 82(12):999-1006.

IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press.

IOM and NRC (National Research Council). 2009. *Weight gain during pregnancy: Reexamining the guidelines*. Washington, DC: The National Academies Press.

Klein, P. D., W. P. James, W. W. Wong, C. S. Irving, P. R. Murgatroyd, M. Cabrera, H. M. Dallosso, E. R. Klein, and B. L. Nichols. 1984. Calorimetric validation of the doubly-labelled water method for determination of energy expenditure in man. *Human Nutrition: Clinical Nutrition* 38(2):95-106.

Lam, Y. Y., and E. Ravussin. 2016. Analysis of energy metabolism in humans: A review of methodologies. *Molecular Metabolism* 5(11):1057-1071.

Lederman, S. A., A. Paxton, S. B. Heymsfield, J. Wang, J. Thornton, and R. N. Pierson, Jr. 1997. Body fat and water changes during pregnancy in women with different body weight and weight gain. *Obstetrics and Gynecology* 90(4 Pt 1):483-488.

Little, R. J., and D. B. Rubin. 2019. *Statistical analysis with missing data*. Hoboken, NJ: John Wiley & Sons.

Manning-Dalton, C., and L. H. Allen. 1983. The effects of lactation on energy and protein consumption, postpartum weight change and body composition of well-nourished North American women. *Nutrition Research* 3(3):293-308.

Meek, J. Y., L. Noble, and the Section on Breastfeeding. 2022. Policy statement: Breastfeeding and the use of human milk. *Pediatrics* 150(1).

Melanson, E. L., T. Swibas, W. M. Kohrt, V. A. Catenacci, S. A. Creasy, G. Plasqui, L. Wouters, J. R. Speakman, and E. S. F. Berman. 2018. Validation of the doubly labeled water method using off-axis integrated cavity output spectroscopy and isotope ratio mass spectrometry. *American Journal of Physiology: Endocrinology and Metabolism* 314(2):E124-E130.

Mossavar-Rahmani, Y., P. A. Shaw, W. W. Wong, D. Sotres-Alvarez, M. D. Gellman, L. Van Horn, M. Stoutenberg, M. L. Daviglus, J. Wylie-Rosett, A. M. Siega-Riz, F. S. Ou, and R. L. Prentice. 2015. Applying recovery biomarkers to calibrate self-report measures of energy and protein in the Hispanic Community Health Study/Study of Latinos. *American Journal of Epidemiology* 181(12):996-1007.

Most, J., M. S. Amant, D. S. Hsia, A. D. Altazan, D. M. Thomas, L. A. Gilmore, P. M. Vallo, R. A. Beyl, E. Ravussin, and L. M. Redman. 2019. Evidence-based recommendations for energy intake in pregnant women with obesity. *Journal of Clinical Investigation* 129(11):4682-4690.

Myles, P. S., and J. Cui. 2007. Using the Bland-Altman method to measure agreement with repeated measures. *British Journal of Anaesthesia* 99(3):309-311.

Naismith, D. J., and C. D. Ritchie. 1975. The effect of breast-feeding and artificial feeding on body-weights, skinfold measurements and food intakes of forty-two primiparous women. *Proceedings of the Nutrition Society* 34(3):116A-117A.

NHLBI/NIDDK (National Heart, Lung, and Blood Institute/National Institute of Diabetes and Digestive and Kidney Diseases). 1998. *Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. The evidence report.* NIH publication no. 98-4083. Bethesda, MD: NIDDK.

Pereira, L. C. R., S. A. Purcell, S. A. Elliott, L. J. McCargar, R. C. Bell, P. J. Robson, C. M. Prado, and T. Enrich Study. 2019. The use of whole body calorimetry to compare measured versus predicted energy expenditure in postpartum women. *American Journal of Clinical Nutrition* 109(3):554-565.

Ravussin, E., I. T. Harper, R. Rising, and C. Bogardus. 1991. Energy expenditure by doubly labeled water: Validation in lean and obese subjects. *American Journal of Physiology* 261(3 Pt 1):E402-E409.

Reilly, J. J., S. Ashworth, and J. C. K. Wells. 2005. Metabolisable energy consumption in the exclusively breast-fed infant aged 3–6 months from the developed world: A systematic review. *British Journal of Nutrition* 94(1):56-63.

Rubin, D. B. 1987. *Multiple imputation for nonresponse in surveys*. New York: John Wiley & Sons.

Sadurskis, A., N. Kabir, J. Wager, and E. Forsum. 1988. Energy metabolism, body composition, and milk production in healthy Swedish women during lactation. *American Journal of Clinical Nutrition* 48(1):44-49.

Schoeller, D. A., and P. Webb. 1984. Five-day comparison of the doubly labeled water method with respiratory gas exchange. *American Journal of Clinical Nutrition* 40(1):153-158.

Schoeller, D. A., E. Ravussin, Y. Schutz, K. J. Acheson, P. Baertschi, and E. Jéquier. 1986. Energy expenditure by doubly labeled water: Validation in humans and proposed calculation. *American Journal of Physiology* 250(5 Pt 2):R823-R830.

Schofield, W. N. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Human Nutrition: Clinical Nutrition* 39(Suppl 1):5-41.

Schutz, Y., and E. Jequier. 1998. Resting energy expenditure, thermic effect of food, and total energy expenditure. In *Handbook of obesity*, edited by G. A. Bray, C. Bouchard, and W. P. T. James. New York: Marcel Dekker.

Seale, J. L., J. M. Conway, and J. J. Canary. 1993. Seven-day validation of doubly labeled water method using indirect room calorimetry. *Journal of Applied Physiology (1985)* 74(1):402-409.

Sohlstrom, A., and E. Forsum. 1995. Changes in adipose tissue volume and distribution during reproduction in Swedish women as assessed by magnetic resonance imaging. *American Journal of Clinical Nutrition* 61(2):287-295.

Sorlie, P. D., L. M. Aviles-Santa, S. Wassertheil-Smoller, R. C. Kaplan, M. L. Daviglus, A. L. Giachello, N. Schneiderman, L. Raij, G. Talavera, M. Allison, L. Lavange, L. E. Chambless, and G. Heiss. 2010. Design and implementation of the Hispanic Community Health Study/Study of Latinos. *Annals of Epidemiology* 20(8):629-641.

Speakman, J. R., Y. Yamada, H. Sagayama, E. S. F. Berman, P. N. Ainslie, L. F. Andersen, L. J. Anderson, L. Arab, I. Baddou, K. Bedu-Addo, E. E. Blaak, S. Blanc, A. G. Bonomi, C. V. C. Bouten, P. Bovet, M. S. Buchowski, N. F. Butte, S. Camps, G. L. Close, J. A. Cooper, S. A. Creasy, S. K. Das, R. Cooper, L. R. Dugas, C. B. Ebbeling, U. Ekelund, S. Entringer, T. Forrester, B. W. Fudge, A. H. Goris, M. Gurven, C. Hambly, A. El Hamdouchi, M. B. Hoos, S. Hu, N. Joonas, A. M. Joosen, P. Katzmarzyk, K. P. Kempen, M. Kimura, W. E. Kraus, R. F. Kushner, E. V. Lambert, W. R. Leonard, N. Lessan, D. S. Ludwig, C. K. Martin, A. C. Medin, E. P. Meijer, J. C. Morehen, J. P. Morton, M. L. Neuhouser, T. A. Nicklas, R. M. Ojiambo, K. H. Pietiläinen, Y. P. Pitsiladis, J. Plange-Rhule, G. Plasqui, R. L. Prentice, R. A. Rabinovich, S. B. Racette, D. A. Raichlen, E. Ravussin, R. M. Reynolds, S. B. Roberts, A. J. Schuit, A. M. Sjödin, E. Stice, S. S. Urlacher, G. Valenti, L. M. Van Etten, E. A. Van Mil, J. C. K. Wells, G. Wilson, B. M. Wood, J. Yanovski, T. Yoshida, X. Zhang, A. J. Murphy-Alford, C. U. Loechl, E. L. Melanson, A. H. Luke, H. Pontzer, J. Rood, D. A. Schoeller, K. R. Westerterp, and W. W. Wong. 2021. A standard calculation methodology for human doubly labeled water studies. *Cell Reports Medicine* 2(2):100203.

van Raaij, J. M., C. M. Schonk, S. H. Vermaat-Miedema, M. E. Peek, and J. G. Hautvast. 1991. Energy cost of lactation, and energy balances of well-nourished Dutch lactating women: Reappraisal of the extra energy requirements of lactation. *American Journal of Clinical Nutrition* 53(3):612-619.

Weir, J. B. 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *Journal of Physiology* 109(1-2):1-9.

Westerterp, K. R. 2001. Limits to sustainable human metabolic rate. *Journal of Experimental Biology* 204(Pt 18):3183-3187.

Westerterp, K. R., F. Brouns, W. H. Saris, and F. ten Hoor. 1988. Comparison of doubly labeled water with respirometry at low- and high-activity levels. *Journal of Applied Physiology* (1985) 65(1):53-56.

WHO (World Health Organization). 1985. *Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation.* World Health Organization Technical Report Series 724:1-206.

WHO. 1998. *Obesity: Preventing and managing the global epidemic: Report of a WHO consultation on obesity, Geneva, 3-5 June 1997*. Geneva: World Health Organization.

WHO. 2021. *Infant and young child feeding*. https://www.who.int/news-room/fact-sheets/detail/infant-and-young-child-feeding (accessed November 14, 2022).

WHO. 2022. *Weight-for-length tables*. https://www.who.int/tools/child-growth-standards/standards/weight-for-length-height (accessed November 28, 2022).

Wong, W. W., S. B. Roberts, S. B. Racette, S. K. Das, L. M. Redman, J. Rochon, M. V. Bhapkar, L. L. Clarke, and W. E. Kraus. 2014. The doubly labeled water method produces highly reproducible longitudinal results in nutrition studies. *Journal of Nutrition* 144(5):777-783.

Wosje, K. S., and H. J. Kalkwarf. 2004. Lactation, weaning, and calcium supplementation: Effects on body composition in postpartum women. *American Journal of Clinical Nutrition* 80(2):423-429.

Yin, P., and X. Fan. 2001. Estimating r 2 shrinkage in multiple regression: A comparison of different analytical methods. *Journal of Experimental Education* 69(2):203-224.

6

Assessing Energy Intakes, Physical Activity, and Indicators of Overweight and Obesity

In this chapter, the committee discusses the *intake assessment component* of the DRI organizing framework described in Chapter 2, which involves an assessment of the current intakes and energy status among U.S. and Canadian life-stage groups and provides background information for Chapter 8 on evaluating the relationships between weight status and the risk of chronic diseases and other adverse health outcomes. In this context, weight gain that places an individual in the overweight or obese BMI category is indicative of long-term energy imbalance that is associated with increased risk for chronic disease. In approaching this chapter, the committee evaluated direct estimates of energy intakes and indicators of adiposity. The committee also evaluated methodological challenges involved in assessing both energy intake and physical activity expenditures. The inclusion of a chapter that focuses on intake and status assessments of the U.S. and Canadian populations is one of four key components of the DRI organizing framework that is now a routine component of the DRI process, as described in Chapter 2.

APPROACH TO ASSESSING ENERGY INTAKES AND PHYSICAL ACTIVITY EXPENDITURES

As part of its task, the committee considered methods used to estimate energy intakes and physical activity and to evaluate the prevalence of long-term energy intake imbalances. The committee began by discussing methodological challenges in estimating intakes and physical activity levels. To assess the status of energy intakes among U.S. and Canadian life-stage groups, the committee used nationally representative population-based health surveys from the U.S. National Health and Nutrition Examination Survey (NHANES), the Canadian Health Measures Survey (CHMS), and the Canadian Community Health Survey (CCHS) to present data on self-reported energy intakes within the EER context as presented in Chapter 5, as well as relying upon indicators of long-term intake imbalances as measured by anthropometry and bone density scan (DXA) for body weight and adiposity. Data on physical activity behaviors for the United States and Canada from NHANES and CHMS were not provided directly to the committee and thus, prevalence on meeting guidelines or average activity levels were obtained from published articles. These population-based data provide background information for subsequent discussions in Chapter 8 on the public health risks associated with energy intake imbalances among population groups.

METHODS FOR ASSESSING ENERGY INTAKE

Self-Reported Dietary Assessment

Accurate dietary assessment methods are needed to identify not only intake deviations from EERs, but also to relate energy intakes to health outcomes in research contexts. These data can then be used to develop public policies and recommendations aimed to reduce the risk of chronic disease. Clinicians and nutrition professionals also use such data to plan menus at the individual and group level. Various means of direct observation exist, but they are not routinely used in research settings. In free-living populations most traditional dietary assessment methods rely on proxy or self-report. Proxy report is mainly used for populations that may depend on caregivers (e.g., young children) or whose literacy level does not meet the requirement for the method of assessment. Self-report is generally regarded as more accurate than proxy reporting in the age range of 8 to 10 years, depending on the memory and attention of the child and how often foods are consumed away from their proxy reporter (Livingstone and Robson, 2000; Livingstone et al., 2004).

Several detailed publications exist to describe the background on current dietary assessment methods (Bailey, 2021; McClung et al., 2018; Thompson et al., 2015). While methods are evolving rapidly in step with technological advances in measuring dietary intakes, advances in image-based and technology-driven dietary assessment have not yet been shown to improve the accuracy of measuring foods and beverages (Ho et al., 2020), or to be equivalent to nontechnological methods (Gemming et al., 2015; Ho et al., 2020). However, another systematic review found that image-assisted methods reduce energy underreporting (Boushey et al., 2017).

Methods of self-reported dietary assessment to estimate energy intakes include 24-hour recall (24HR), food records (FR), and food-frequency questionnaires (FFQ). These are available for administration by phone, in person, or through mobile-, image-, or web-based platforms. In general, the goal of self-report dietary assessment is to provide an estimate of usual intakes (i.e., long-term average or habitual diet) (Kirkpatrick et al., 2018). The 24HR and FR are short-term methods, and FFQs generally tend to capture longer-term intakes. An FR is ideally collected by weighing all foods and beverages consumed, but it is subject to reactivity—that is, when recording food intake, individuals tend to change their usual dietary patterns. A 24HR is currently the least-biased estimator of energy, but because of variability in what people eat, a large number of 24HRs on random days averaged across days of the week and seasons of the year would be needed to provide true estimates of an individual's usual intakes, which is generally impractical (Bailey, 2021; Basiotis et al., 1987; Souverein et al., 2011).

However, given two or more 24HRs on individuals, statistical methods have been developed to provide estimates of the distribution of usual intakes in a group. Although FFQs directly query long-term intake, they are prone to systematic bias. A complete discussion on measurement errors, including systematic bias and methods to improve estimating usual dietary exposures follows. Given that the national surveys examined for this report rely exclusively on 24HR to estimate energy needs, this chapter will primarily focus on the 24HR. More detail on the collection procedures from the 24HRs follows.

Measurement Error with Dietary Assessment

All methods of dietary assessment have measurement error, which is defined as the deviation of an instrument or measurement tool from "truth." Truth in this context is the energy required to maintain body weight and function. Any deviation from truth, then, is considered measurement error. Measurement error is broadly classified into systematic and random, and an error in self-reported dietary assessment is often referred to as misreporting. Understanding of the types and structure of measurement error with regard to dietary energy comes from studies that use doubly labeled water (DLW).

DLW represents a recovery biomarker that approximates energy expenditure; when weight is stable, in theory, energy intake should be similar to that of energy expenditure (Speakman, 1998). It has been estimated that DLW is within 1 to 2 percent of actual expenditure overall (Schoeller and van Santen, 1982), but it may vary during periods of growth and life stages with increased energy needs (e.g., lactation or pregnancy). Chapter 5 provides an in-depth description of the DLW method. DLW validation studies have consistently determined that all self-reported dietary assessment methods are subject to both random error and systematic bias but that 24HRs has less systematic error for reporting energy than FFQs. In addition, statistical methods can be used to adjust for random error.

Random error in regard to energy intake often manifests as within-person variability. This is the difference, for example, of one 24HR when compared with the average of multiple 24HRs for a given individual. Random error decreases precision of an instrument, which can lower statistical power to detect relationships. While random error does not affect the group mean, it does result in a wider estimated distribution of energy intake with wider tails (Gibson, 1990). Collecting a large number of 24HRs is impractical, but several statistical modeling techniques have been developed to isolate the random error and estimate a distribution of usual intake using as few as two 24HRs per person.

If multiple recall days are not available for all members of a group, a representative subset from the group can be used, or external—but representative—data can also be used. A number of approaches have been developed to estimate the distribution of usual intakes when only a small number of 24HRs are available per individual (Dodd et al., 2006; NRC, 1986; Nusser et al., 1996; Subar et al., 2006; Tooze et al., 2006, 2010). These usual intake methods vary; the data reported herein come from usual intake modeling of national survey data of 24HRs using one of these methods, the National Cancer Institute (NCI) method (Tooze et al., 2006, 2010) (described below).

Systematic error is defined as a deviation from the truth in a specific direction. It causes a change in both the mean and the distribution of a data set. In terms of energy intakes, systematic error often commonly manifests as energy underreporting in adults; but overreporting is also an issue, particularly in younger children. Multiple types of measurement error have been described with self-reported dietary data, including social desirability, intrusions, and omissions. Individuals vary in their memory and ability to estimate portion size as well as their perceived need for social desirability, this is a type of person-specific bias that may relate to certain factors, like age, but is not well characterized and is not predictable (Dwyer et al., 1989).

DATA ON VALIDITY FROM STUDIES WITH DLW FOR ENERGY INTAKE ACROSS THE LIFE COURSE

Chapter 3 provides details on the committee's methodological approach to identify and review relevant scientific literature, as no systematic reviews were provided *a priori*. The committee's literature search identified eight systematic reviews of measurement error in dietary assessment (See Appendix J, Table J-14). One study was excluded because it was not a systematic review and did not include 24HR data. Other systematic reviews were not relevant to the committee's task because the focus was not on 24HR data collected in a manner similar to that of NHANES and CCHS-Nutrition used in this report. One systematic review assessed the validity of food records in athletes and found that energy underreporting across 11 pooled studies was, on average, 19 percent below what was estimated from DLW (Capling et al., 2017). One systematic review examined the ability and validity of children to recall specific meal occasions only (Tugault-Lafleur et al., 2017).

One systematic review of image-assisted methods (i.e., use of a handheld [$n = 10$] or wearable camera [$n = 3$]) of dietary assessment among adults found that these methods as a primary assessment tool tended to underestimate energy intake and that image-assisted 24HR recalls tended to overestimate energy intake (Gemming et al., 2015). The systematic review determined that future work would need to be conducted in different age groups than were examined (ranging from 18 to 70 years). A similar systematic review of image-based dietary assessments ($n = 13$) also confirmed that these tools are not inferior to more traditional methods, but similarly result in substantial energy underreporting (Ho et al., 2020). One systematic review specifically focused on adults with a body mass index (BMI) greater than or equal to 30 found significant underreporting of food intake; however, only one study focused on comparing energy intake from 24HR relative to energy expenditure determined using DLW, and it was conducted outside of North America (Wehling and Lusher, 2019).

Another systematic review of the validity of dietary assessment methods compared to DLW specifically in children did not include any studies with traditional 24HR methods but found that among children and adolescents, the accuracy of energy reporting was not related to the sex, age, or weight status of the child (Burrows et al., 2020), which differs from previous reports (Burrows et al., 2010). Given the limited data on children in these age groups, Burrows et al. (2020) noted that more data are needed on children from diverse ethnic and socioeconomic backgrounds given the limited scope of the available data.

A systematic review of the validity of dietary assessment methods compared to DLW specifically in children concluded that 24HRs were valid for energy intake reporting at the group but not at the individual level and that the accuracy of energy reporting was not related to the sex, age, or weight status of the child (Burrows et al., 2020), which differs from previous reports (Burrows et al., 2010).

A systematic review of studies in adults included seven studies with DLW and 24HR, evaluated by sex. This review found that energy underreporting may vary based on participant characteristics; for example, all seven studies suggest that women are more likely to underreport energy intake but only two suggested there was a differential reporting by body weight status (i.e., individuals with overweight and obesity had more underreporting) (Burrows et al., 2019). The range of underreporting on the 24HR was 8 to 30 percent. Overall, there were 59 studies, the majority of which used FFQs (*n* = 21) or FR (*n* = 36) as the dietary assessment tool and DLW, and five studies used a diet history method (Burrows et al., 2019). Energy underreporting was 4.6 to 42 percent using FFQ data, and this varied by the type of questionnaire that was used. The FR estimates range from 11 to 41 percent energy underreporting and estimates for diet histories ranged from 1.3 to 47 percent. The authors concluded that the 24HR is the method with the least amount of variation in estimates and the least amount of underreporting. Energy underreporting remains pervasive, however, and is an important source of bias in self-reported dietary assessment (Burrows et al., 2019). More data are also needed on children from diverse ethnic and socioeconomic backgrounds.

METHODS FOR ASSESSING PHYSICAL ACTIVITY

Physical activity can be viewed as a continuum of trade-offs to consider when selecting a physical behavior assessment method based on validity, participant and researcher burden, cost, practicality, and feasibility (Figure 6-1).

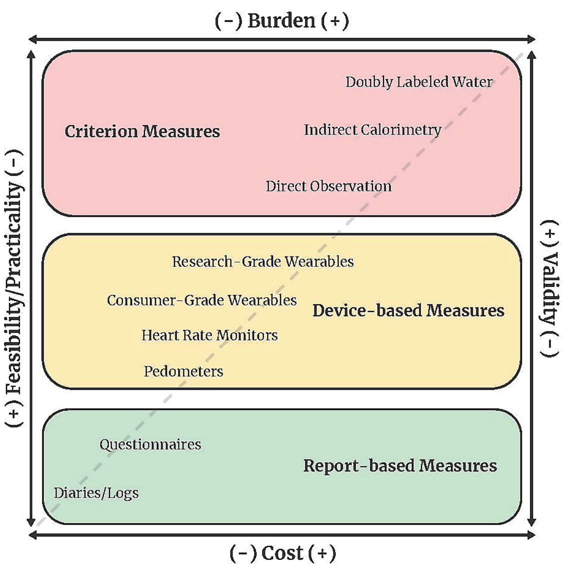

FIGURE 6-1 Physical behavior assessment tool continuum of trade-offs in decision making to select a physical behavior assessment tool.
SOURCE: Reprinted from Crouter S. E., Hibbing P. R., and S. R. LaMunion. In Press. Physical activity assessment. In: Raynor HA, Gigliotti L, eds. *Health Professional's Guide to Obesity and Weight Management*. Chicago, IL: Academy of Nutrition and Dietetics, with permission from The Academy of Nutrition and Dietetics.

Doubly Labeled Water and Indirect Calorimetry

DLW and indirect calorimetry are considered the primary methods for measuring energy expenditure (Dowd et al., 2018; Strath et al., 2013; Sylvia et al., 2014). DLW is ideal for measuring total daily energy expenditure in free-living individuals because it has low subject burden and does not interfere with daily activities. It lacks temporal resolution for examination of shorter time periods (e.g., hours), however, and is costly (Sylvia et al., 2014). Indirect calorimetry has multiple applications (e.g., whole-room metabolic chamber, metabolic systems with a face mask).

Whole-room metabolic chambers can last for a few hours up to several days and provide temporal time resolution to examine different components of energy expenditure (e.g., sleep, activity energy expenditure, thermic effect of feeding). Portable indirect calorimeters allow for a broader range of activities to be captured and can be used in free-living applications (Macfarlane, 2017; Overstreet et al., 2017; Schoffelen et al., 2019). Use of indirect calorimetry is typically found in high-level research and clinical spaces and requires a multidisciplinary team to operate.

To more practically assess free-living physical activity, report-based methods (e.g., self-report questionnaires) and device-based methods (e.g., pedometers, accelerometer-based devices) are typically used. These methods are validated against DLW and indirect calorimetry. In general, device-based methods provide better estimates of total energy expenditure compared to report-based methods.

Self-Report Estimates of Physical Activity

Several systematic reviews have explored comparisons of self-report estimates of total energy expenditure to estimates via DLW. Adamo et al. (2009) found that self-report measures (activity diaries or logs, questionnaires, surveys, and recall interviews) in general overestimated physical activity or energy expenditure (compared to DLW) in both boys and girls by an average of 22 percent (range, 25 to 78 percent). Helmerhorst et al. (2012) also found in youth less than 18 years of age that self-report measures and DLW had Spearman *r* that ranged from 0.49 to 0.65 for total energy expenditure, with a mean difference of 2,800 kJ/day.

In adults, Dowd et al. (2018) found that compared to DLW, mean percent differences for self-reported physical activity measures from the previous past 12 months ranged from –77.6 to 112.5 percent. Specifically, reports of physical activity from diaries ranged from 12.9 to 20.8 percent. Self-reported physical activity energy expenditure recalled from the previous 7 days ranged from –59.5 to 62.1 percent and self-reported physical activity energy expenditure for the previous month ranged from –13.3 to 11.4 percent.

Helmerhorst et al. (2012) found that, in adults, TEE from DLW compared to self-report measures had a Spearman correlation that ranged from 0.15 to 0.47 (Pearson correlation ranged from 0.12 to 0.69) and mean differences ranged from 3,451.9 to 7,455 kJ/day. In older adults (older than 65 years), Helmerhorst et al. found that TEE for DLW compared to self-report measures had a Spearman correlation that ranged from 0.10 to 0.64 (Pearson correlation ranged from 0.11 to 0.65) and mean differences ranged from 435 to 3,146 kJ/day for men and 37 to 2,037 kJ/day for women.

Device-Based Estimates of Physical Activity

Several systematic reviews have explored how device-based estimates from wearable physical activity monitors compare to DLW and indirect calorimetry. Dowd et al. (2018) compared activity monitor energy expenditure to DLW, indirect calorimetry, and whole-room calorimetry. In this review, activity monitor estimates compared to DLW had a mean percent difference ranging from 56.6 to 96.8 percent. However, a trend for activity monitor–determined energy expenditure to underestimate the criterion measure of energy expenditure by DLW was found. For indirect calorimetry and whole-room calorimetry, activity monitor estimates of energy expenditure mean percent differences ranged from 41.4 to 115.7 percent (indirect calorimetry) and –16.7 to –15.7 percent (whole-room calorimetry).

O'Driscoll et al. (2020) examined energy expenditure estimates of wrist and arm devices (40 different devices, 33 worn on the wrist) compared to DLW, indirect calorimetry, and room calorimetry. Overall, the devices underestimated energy expenditure (effect size: –0.23, 95% CI, –0.44 to –0.03; $n = 104$; $p = .03$) and showed significant heterogeneity between devices ($I^2 = 92.18\%$; $p \leq .001$). For those devices that were compared only to DLW (10 different devices), the pooled effect for TEE showed that energy expenditure was significantly underestimated (effect size: –0.68, 95% CI, –1.15 to –0.21; $n = 16$; $p = .005$), and significant heterogeneity was observed between devices ($I^2 = 92.71\%$; $p < .01$).

Fewer data are available for pedometers and counting. Dowd et al. (2018) compared pedometer-determined energy expenditure to DLW. In free-living studies, pedometers were worn for 2 and 8 days and had mean percent errors ranging from –62.3 percent to –0.8 percent. A systematic review by Tudor-Locke et al. (2002) examined pedometer values compared to DLW. A single study comparing pedometer outputs with energy expenditure derived from DLW reported a significant correlation of $r = 0.61$ in a patient population; however, two other studies reported no significant correlations in different populations (no r values reported). Tudor-Locke et al. (2002) also reported that pedometers generally correlated with indirect calorimetry ($r = 0.49$ to 0.81).

DESCRIPTION OF U.S. AND CANADIAN NATIONAL SURVEYS

National surveillance data in the United States and Canada use the 24HR method to assess energy intakes. For this report, data on U.S. energy intakes and various body composition measures were estimated using the 2015–2018 NHANES. Data from Canada were examined from two sources: the 2015 CCHS and the CHMS, cycles 3 to 6 (January 2012 to December 2019). Data on energy intakes for the populations were estimated from NHANES and CCHS, whereas anthropometry data were examined using NHANES and CHMS. NHANES operates on a continuous basis in 2-year cycles. CHMS also collects data in 2-year cycles, whereas CCHS has periodic data collection. The survey years for three data sets were chosen for the report because of the temporal proximity between the two countries. Complete details on how the surveys operate are detailed online for CCHS,[1] CHMS,[2] and NHANES[3] and described briefly herein.

National Health and Nutrition Examination Survey (NHANES)

NHANES is a nationally representative survey designed to assess the health and nutritional status of adults and children in the United States. Through interviews and physical examinations, the survey collects demographic, socioeconomic, dietary, and health-related information, as well as medical, dental, and physiological measurements and laboratory tests. NHANES collects information on demographic and lifestyle factors of the household during an in-home interview, anthropometric and dietary data during a visit to a mobile examination center, and additional dietary data during the follow-up telephone interview. Details of the interview process are in Appendix K.

Canadian Community Health Survey

The CCHS is a joint effort of Health Canada, the Public Health Agency of Canada, Statistics Canada, and the Canadian Institute for Health Information. Since 2000, this annual survey has collected population-level data on health determinants, health status, and health system use. In addition to the annual survey, occasional survey modules (the most recent in 2015) have focused on food- and nutrition-related data such as nutrient intakes, food insecurity, and anthropometric measures.

---

[1] https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs.html (accessed February 8, 2023).

[2] https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5071&lang=en&db=imdb&adm=8&dis=2 (accessed February 8, 2023).

[3] https://www.cdc.gov/nchs/nhanes/about_nhanes.htm (accessed February 8, 2023).

The 2015 CCHS-Nutrition is a nationally representative cross-sectional survey of the civilian Canadian population (aged 1 year or more; residing in the 10 provinces) that uses a complex, multistage cluster sampling design.[4] This was the first cycle since 2004 to comprehensively collect dietary data. Results are available for 13 geographic areas: Canada excluding the territories, the 10 provinces, the Atlantic Region, and the Prairie Region. Data from the four Atlantic Provinces and the three Prairie Provinces were combined into the Atlantic Region and the Prairie Region, respectively. Details of the interview process are in Appendix K.

Canadian Health Measures Survey

Statistics Canada, in partnership with Health Canada and the Public Health Agency of Canada, has conducted the CHMS every 2 years since 2007. This ongoing, nationally representative survey collects information at 16 randomly selected sites across Canada on nutritional status, fitness, chronic diseases, environmental exposures, and other health measures. Physical measurements such as height, weight, and physical fitness are also collected. The CHMS uses a complex, multistage cluster sampling design and is designed to collect health-related information of the general public. Active members of the military are excluded, as are residents of Indian reserves, Crown lands, and remote regions.

Each survey cycle includes approximately 5,000 Canadians and consists of a detailed health questionnaire administered in the home by a trained interviewer (using the Computer-Assisted Personal Interviewing system), in which participants are asked to provide detailed information on sociodemographic characteristics, dietary supplement use, chronic and infectious disease, nutrition, and environmental factors, as well as a clinic visit in the mobile examination center approximately 1 day to 6 weeks after the in-home interview. Written consent is obtained for all participants and/or their proxies for all procedures carried out by CHMS. The Health Canada Research Ethics Board approves the CHMS protocol. Details of the interview process are in Appendix K.

COMPARISON OF ENERGY INTAKE AND EXPENDITURE AMONG U.S. AND CANADIAN POPULATIONS

Usual Energy Intake Data

The National Cancer Institute (NCI) method (Tooze et al., 2006, 2010) was used to estimate usual energy intakes in both U.S. and Canadian

[4] https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5049 (accessed February 8, 2023).

national surveys. The NCI method macros are publicly available. In both countries, these models excluded from the age group estimates pregnant and lactating women as well as infants and young children receiving breast milk (and presents those groups separately) and included day of the week (i.e., weekday and weekend day) and sequence of the recall as covariates. Estimates of usual energy intakes by sex and age are presented in Tables 6-1 and 6-2. Estimates that are considered statistically unreliable, based on the relative standard error, are not presented. To facilitate comparisons between the two countries, *Z* statistics were computed and significance was assumed at an alpha of 0.05. The complete data tables on dietary intake prepared for the committee by the Centers for Disease Control and Prevention (CDC) and Statistics Canada are provided in supplemental Appendix X.[5] Examples of applying the EER equations to exemplar age/sex and life-stage groups are provided in Chapter 7.

Mean usual energy intakes were compared by age and sex groups between the United States and Canada for those ages 4 years and older. For those younger than 30 years, the only significant difference in energy intakes between countries existed for 4-to-8-year-old boys. Among adults, for both men and women, higher usual mean energy intakes were reported among Americans when compared with Canadians. Among children when mean energy intake was compared between age/sex groups by country, boys had higher usual mean energy intakes than girls. A similar significant trend was observed within country and age group by sex among adults. In both countries and across age groups, reported energy intakes were well below the EER.

INDICATORS OF BODY WEIGHT AND ADIPOSITY

Given that self-reported intake data do not accurately reflect recent energy intakes, an alternative approach for estimating long-term energy intakes is to measure body weight and body composition. Higher BMIs and increased adiposity are of public health concern because of their associations with adverse health outcomes (CDC, 2022; Statistics Canada, 2019; WHO, 2021). Nationally representative data on various indicators of body weight and adiposity for the U.S. and Canadian populations from the 2015–2018 NHANES and the 2012–2019 CHMS, respectively, could be used to evaluate energy intake imbalances for EER life-stage groups in the United States and Canada.

[5] Supplemental appendixes are available at https://nap.nationalacademies.org/catalog/26818.

TABLE 6-1 Mean and Percentiles for Usual Daily Intake of Energy (kcal), United States

Sex	Age or Life Stage	N	Mean	SEM	5th %tile	SE	10th %tile	SE	25th %tile	SE	50th %tile	SE	75th %tile	SE	90th %tile	SE	95th %tile	SE
Male	0–6 mo	182	683	23	377	36	435	32	540	25	666	23	817	31	949	42	1,036	51
Female	0–6 mo	187	**		**		**		**		**		**		**		**	
Male	7–12 mo	141	**		**		**		**		**		**		1,126*	53	1,214*	56
Female	7–12 mo	137	**		**		**		**		**		**		**		**	
Male	2–3 y	585	1,441	44	1,006	84	1,088	76	1,237	65	1,424	52	1,624	37	1,814	45	1,946	58
Female	2–3 y	531	1,355	61	938	96	1,014	87	1,165	84	1,337	68	1,524	45	1,716	38	1,838	43
Male	4–8 y	720	1,853	45	1,329	96	1,430	90	1,613	70	1,830	50	2,069	34	2,304	47	2,446	71
Female	4–8 y	731	1,650	46	1,180	107	1,269	98	1,438	86	1,626	52	1,840	26	2,054	37	2,197	54
Male	9–13 y	740	2,043	54	1,294	89	1,432	82	1,691	69	2,004	57	2,352	53	2,696	60	2,933	82
Female	9–13 y	770	1,895	63	1,194	97	1,317	95	1,558	85	1,859	63	2,189	56	2,518	54	2,716	66
Male	14–18 y	715	2,344	127	1,527	51	1,683	63	1,956	84	2,300	118	2,689	164	3,066	213	3,302*	247
Female	14–18 y	706	1,793	54	1,116	44	1,239	40	1,469	38	1,758	51	2,080	80	2,396	104	2,603	136
Male	19–30 y	919	2,463	47	1,528	95	1,695	84	2,017	74	2,414	51	2,854	43	3,293	61	3,572	80
Female	19–30 y	904	1,823	74	1,130	31	1,272	29	1,515	38	1,797	72	2,111	103	2,404	147	2,580	174
Male	31–50 y	1,469	2,602	77	1,630	132	1,812	122	2,140	104	2,548	81	3,006	58	3,469	59	3,754	64
Female	31–50 y	1,564	1,864	21	1,171	64	1,305	57	1,551	42	1,836	21	2,150	35	2,452	70	2,641	96
Male	51–70 y	1,700	2,379	108	1,461	36	1,628	42	1,938	69	2,330	104	2,765	150	3,195	190	3,478	209
Female	51–70 y	1,745	1,750	73	1,081	26	1,212	24	1,444	36	1,724	68	2,028	107	2,319	148	2,510	162
Male	> 70 y	762	2,206	32	1,338	82	1,505	81	1,799	59	2,162	32	2,562	51	2,965	90	3,226	116

Female	> 70 y	750	1,621	79	973	31	1,104	32	1,331	42	1,598	76	1,883	118	2,170	153	2,347	171
Male	19+	4,850	2,454	19	1,497	63	1,674	54	1,999	36	2,403	19	2,853	41	3,301	72	3,594	83
Female	19+	4,963	1,783	48	1,096	30	1,230	20	1,469	20	1,758	42	2,068	78	2,367	116	2,555	137
Female	Lactating	78	**		**		**		**		**		**		**		**	
Female	Pregnant	111	**		**		**		**		**		**		**		**	
Female	Pregnant or Lactating	189	**		**		**		**		**		**		**		**	

NOTES: kcal = kilocalorie; mo = months; %ile = percentile; SE = standard error; SEM = standard error of the mean; y = years. Includes participants with reliable 24-hour dietary recall on day 1 and breastfeeding children with dietary recall status = reported consuming breast milk and have dietary data; estimates other than for pregnant and lactating women adjusted for age, day of the week, and weekend. Selected percentiles are provided in this table, see the Supplemental Appendix Table X-1 for the complete set of percentiles. The expanded set of related tables is also available in Supplemental Appendix X.

* Estimate has a relative standard error greater than 30% but less than 40% and should be used with caution because it does not meet National Center for Health Statistics (NCHS) standards of reliability or precision.

** Estimate has a relative standard error greater than 40% and does not meet NCHS standards of reliability or precision.

SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

TABLE 6-2 Total Energy Intake (kcal/d): Usual Intake from Food, Canada, 2015

Sex	Age or Life Stage	*n*	Mean	SEM	5th %tile	SE	10th %tile	SE	25th %tile	SE	50th %tile	SE	75th %tile	SE	90th %tile	SE	95th %tile	SE
Male	1–3 y	665	1,367	25	858	148*	954	120	1,134	70	1,347	26	1,578	67	1,807	132	1,946	172
Female	1–3 y	623	1,261	28	766	150*	865	121	1,038	73	1,244	30	1,464	61	1,675	120	1,813	160
Male	4–8 y	590	1,739	27	1,310	89	1,396	75	1,546	51	1,723	29	1,918	39	2,097	72	2,210	96
Female	4–8 y	609	1,602	30	1,201	81	1,283	68	1,418	47	1,590	30	1,769	44	1,944	76	2,048	99
Male	9–13 y	1,023	2,057	34	1,340	62	1,477	55	1,718	44	2,014	35	2,355	41	2,691	61	2,908	78
Female	9–13 y	939	1,839	31	1,246	46	1,357	42	1,560	35	1,810	32	2,084	40	2,357	54	2,538	66
Male	14–18 y	900	2,483	51	1,527	63	1,701	58	2,026	52	2,422	49	2,878	65	3,337	98	3,654	126
Female	14–18 y	986	1,819	39	1,083	60	1,222	53	1,477	44	1,785	39	2,122	50	2,461	73	2,678	91
Male	19–30 y	857	2,409	71	1,507	109	1,677	97	1,984	78	2,367	70	2,783	95	3,199	139	3,472	173
Female	19–30 y	872	1,679	45	982	47	1,105	45	1,336	43	1,636	44	1,974	55	2,306	72	2,526	86
Male	31–50 y	2,005	2,226	34	1,313	132	1,482	108	1,790	67	2,177	35	2,605	62	3,035	122	3,314	165
Female	31–50 y	2,207	1,638	26	1,122	91	1,221	77	1,400	51	1,616	28	1,852	44	2,084	83	2,229	111
Male	51–70 y	2,151	2,070	37	1,251	89	1,404	75	1,686	51	2,028	37	2,408	56	2,783	92	3,031	118
Female	51–70 y	2,314	1,577	21	980	167*	1,092	135	1,297	76	1,552	22	1,826	59	2,093	132	2,264	183
Male	71 y and over	1,180	1,806	27	1,076	38	1,220	34	1,471	29	1,775	28	2,107	33	2,431	45	2,635	55
Female	71 y and over	1,448	1,418	24	876	27	978	25	1,162	23	1,392	23	1,643	31	1,892	41	2,048	50
Female	Pregnant	114	1,947	77	1,344	192	1,462	163	1,673	115	1,918	80	2,194	106	2,451	172	2,649	226

Female	Lactating	187	1,927	64	1,313	188	1,434	158	1,657	107	1,916	66	2,180	96	2,430	166	2,587	215
Female	Pregnant or lactating	301	1,935	55	1,327	200	1,446	167	1,663	108	1,917	58	2,186	90	2,438	167	2,611	226
Male	19 y and over	6,193	2,162	23	1,242	30	1,409	28	1,720	24	2,110	23	2,545	29	2,983	41	3,260	51
Female	19 y and over	6,841	1,591	15	980	27	1,094	24	1,303	19	1,562	15	1,847	19	2,129	30	2,306	38
Both sexes	19 y and over	13,034	1,879	14	1,035	17	1,182	16	1,461	14	1,821	14	2,233	18	2,653	26	2,927	32

NOTES: d = day; kcal = kilocalorie; SE = standard error; SEM = standard error of the mean; y = years. Excluded from the data set were respondents with null intakes (zero total intake from food) or invalid intakes, breastfed children and pregnant or breastfeeding women. Selected percentiles are provided in this table, see the Supplemental Appendix Table X-8 for the complete set of percentiles. The expanded set of related tables is also available in Supplemental Appendix X.

* Data with a coefficient of variation (CV) from 16.6% to 33.3%; interpret with caution.

SOURCES: Summary data table of estimates of usual intakes for energy, nutrients and other dietary components from food, using data collected from Canadians in the 2015 Canadian Community Health Survey (CCHS) - Nutrition. Health Canada (2019). Usual Intakes from Food for Energy, Nutrients and Other Dietary Components (2004 and 2015 CCHS-Nutrition) derived from Statistics Canada's 2004 and 2015 Canadian Community Health Survey, Nutrition, Share file. Ottawa. https://open.canada.ca/data/en/dataset/31599960-2c1e-4d90-a9d9-979ad0e1abb4. Statistics Canada, Canadian Community Health Survey (CCHS) - Nutrition 2015 Share File.

Heights and Weights of U.S. and Canadian Populations

Measures of height and weight are values used in equations to estimate EERs and to calculate BMI. The heights and weights for U.S. and Canadian life-stage groups are shown in Tables 6-3 and 6-4. (See Supplemental Appendix Y for weight and height distributions across all age/sex groups and among race/ethnic groups.) Canadian boys 9 to 13 and 14 to 18 were taller than their U.S. counterparts, with differences ranging from 1.4 to 2.0 cm (0.5 to 0.8 in.) for these two groups. Similarly, Canadian girls were taller than their U.S. counterparts except for those 9 to 13 years, with differences ranging from 1.4 to 1.9 cm (0.5 to 0.7 in.). Conversely, Canadian boys aged 4 to 8 and 9 to 13 weighed less than U.S. boys, with differences ranging from 1.2 to 2.5 kg (2.6 to 5.5 lb). Canadian girls 9 to 18 years of age weighed less than U.S. girls, with differences ranging from 3.0 to 4.4 kg (6.6 to 9.7 lb).

For adults, Canadian men 19 years and older were taller than their U.S. counterparts—175.3 versus 176.0 cm, a difference of approximately 0.3 inches. Similarly, Canadian women 19 years and older were taller than their U.S. counterparts by 1 cm (0.4 in.). U.S. men and women 19 years and older weighed more than their Canadian counterparts, with a difference of 4.5 kg (9.9 lb) for men and 5.9 kg (13 lb) for women.

TABLE 6-3 Mean Heights and Weights, U.S. and Canadian Children

Age (years)	Height (cm) Mean (SE)		Weight (kg) Mean (SE)	
	United States	Canada	United States	Canada
Males				
3	99.1 (0.4)	100.1 (0.4)	16.6 (0.4)	16.2 (0.2)
4–8	119.9 (0.5)	120.2 (0.4)	25.0 (0.4)	23.8 (0.3)*
9–13	149.0 (0.5)	150.4 (0.4)*	46.7 (0.6)	44.2 (0.4)*
14–18	172.9 (0.3)	174.9 (0.4)*	72.1 (1.0)	72.7 (1.5)
Females				
3	97.5 (0.4)	99.4 (0.4)*	15.4 (0.2)	16.0 (0.2)*
4–8	117.5 (0.4)	118.9 (0.4)*	24.1 (0.3)	23.5 (0.2)
9–13	148.4 (0.6)	149.3 (0.4)	46.5 (0.7)	43.5 (0.6)*
14–18	162.0 (0.4)	163.6 (0.4)*	65.4 (0.8)	61.0 (0.6)*

NOTES: cm = centimeter; kg = kilogram; SE = standard error. Data are from Appendix Tables L-1, L-2, L-5, L-6 and Supplemental Appendix Tables Y-1 and Y-2. See Supplemental Appendix Y for the expanded set of tables. Because CMHS did not have data on 2-year-olds, the committee excluded 2-year-olds from U.S. data.

*Statistical significance between U.S. and Canadian age/sex groups based on *Z*-score; value > 1.96 ($p < .05$).

SOURCES: National Health and Nutrition Examination Survey (NHANES) 2015–2018; Canadian Health Measures Survey (CHMS) Cycles 3 to 6 (2012 to 2019).

TABLE 6-4 Mean Heights and Weights, U.S. and Canadian Adults

Age (years)	Height (cm) Mean (SE)		Weight (kg) Mean (SE)	
	United States	Canada	United States	Canada
Males				
19–30	175.8 (0.3)	178.2 (0.5)*	86.0 (1.3)	83.3 (1.1)
31–50	176.3 (0.3)	176.6 (0.2)	94.1 (0.8)	87.0 (0.9)*
51–70	174.8 (0.3)	174.7 (0.3)	91.1 (0.7)	86.8 (0.6)*
> 70	172.0 (0.4)	171.7 (0.4)	85.1 (0.9)	83.3 (0.8)
19+	175.3 (0.2)	176.0 (0.2)*	90.4 (0.6)	85.9 (0.5)*
Females				
19–30	162.5 (0.3)	164.0 (0.5)*	74.7 (1.0)	69.0 (1.2)*
31–50	162.5 (0.3)	163.7 (0.3)*	80.7 (1.0)	72.6 (0.9)*
51–70	160.9 (0.3)	160.6 (0.3)	78.3 (0.8)	72.3 (0.7)*
> 70	157.1 (0.3)	158.1 (0.3)*	71.8 (0.8)	69.3 (0.8)*
19+	161.3 (0.2)	162.3 (0.2)*	77.5 (0.6)	71.6 (0.7)*

NOTES: cm = centimeter; kg = kilogram; SE = standard error. Data are from Appendix Tables L-3, L-4, L-7, and L-8. See Supplemental Appendix Y for the expanded set of tables.

*Statistical significance between U.S. and Canadian age/sex groups based on *Z*-score; value > 1.96 ($p < .05$)

SOURCES: National Health and Nutrition Examination Survey (NHANES), 2015–2018; Canadian Health Measures Survey (CHMS) Cycles 3 to 6 (2012 to 2019).

Prevalence of Normal Weight, Overweight, and Obesity in the U.S. and Canadian Populations

As a ratio, BMI can be used to directly compare values across age/sex groups and to classify individuals as underweight, normal weight, overweight, and obese. It is easily measured as it reflects weight (kg) divided by height squared (m^2). However, some caution is needed in using BMI values, as they do not measure fat distribution, which is an important predictor of risk of several adverse health outcomes. Similarly, BMI can misclassify highly muscular individuals as overweight. See the supplemental online Appendix Y for the expanded set of survey data on prevalence for all age/sex groups.

Prevalence of normal weight, overweight, and obesity for U.S. and Canadian children are shown in Table 6-5. Prevalence of underweight for U.S. and Canadian children ranged from 2 to 6 percent and from 3 to 5 percent, respectively (see Appendix Tables L-9, L-10a, and L-10b). Prevalence of normal weight exceeds 50 percent for both U.S. and Canadian children, and prevalence of overweight varies from 15 to 20 percent for U.S. children and 10 to 16 percent for Canadian children. Prevalence of obesity varies from

17 to 23 percent for U.S. children and 9 to 18 percent for Canadian children. Prevalence of normal weight was lower in U.S. children compared to Canadian children in all groups except for 14-to-18-year-old boys. Conversely, prevalence of obesity was higher in U.S. children compared to Canadian children in all groups except for 14-to-18-year-old boys.

Table 6-6 presents similar data for adults, with the addition of a measure of abdominal obesity. Prevalence of underweight ranges from less than 1 percent to 4 percent for U.S. adults, and from less than 1 percent to 5 percent for Canadians (See Appendix Tables L-11 and L-12). For both the United States and Canada, prevalence of normal weight is generally less than 50 percent, indicating that more than half of the adult populations have either overweight or obesity. For U.S. adults, 32 to 45 percent are categorized as having obesity. Canadian adults have lower prevalence of obesity, 19 to 31 percent, than their U.S. counterparts. Within each country, the prevalence of normal weight and overweight generally differs between men and women.

TABLE 6-5 Prevalence of Normal Weight, Overweight, and Obesity, U.S. and Canadian Children

Life-Stage Group	United States	Canada	United States	Canada	United States	Canada
	% Normal (SE)		% Overweight (SE)		% Obesity (SE)	
Males						
4–8 years	64.2 (2.2)	74.1 (1.9)*	15.2 (1.2)	10.5 (1.1)*	17.1 (1.7)	9.1 (1.3)*
9–13 years	58.2 (1.9)	69.1 (2.1)*	15.1 (1.3)	15.9 (1.4)	23.4 (1.8)	11.0 (1.3)*
14–18 years	57.0 (2.4)	62.9 (2.6)	15.8 (1.3)	13.7 (1.7)	20.8 (1.9)	18.4 (2.4)
Females						
4–8 years	64.2 (2.0)	74.5 (1.6)*	14.5 (1.2)	12.9 (1.5)	18.2 (1.7)	9.0 (0.9)*
9–13 years	59.9 (1.9)	71.3 (2.0)*	18.9 (1.7)	15.1 (1.8)	18.7 (1.6)	8.9 (1.1)*
14–18 years	57.4 (2.4)	73.2 (1.7)*	20.6 (1.6)	13.2 (1.5)*	19.5 (1.6)	10.0 (1.1)*

NOTES: SE = standard error. Pregnant and lactating adolescents were excluded from NHANES; pregnant women were excluded from Canadian data. This table does not include % underweight because most of the Canadian estimates for children are unreliable. This table does not include data for 2-to-3 year-old children because Canada has no data for 2-year-olds and most of the available Canadian data are unreliable for the 3-year-old age group. Prevalence values in the table will not add to 100% because the underweight category has not been included in the table. BMI categories for children: underweight: < 5th percentile for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obesity: ≥ 95th percentile. See Appendix Table L-10b for Canadian data on prevalence of weight categories for children using WHO rather than CDC criteria.

*Statistically significant difference between U.S. and Canadian life-stage groups using Z-statistic; Z-score > 1.96, significant at $p < .05$.

SOURCE: From Appendix Tables L-9 and L-10a. See Supplemental Appendix Y for expanded tables.

Abdominal obesity is an indicator of excessive visceral fat around the stomach and abdomen and is associated with an increased risk of adverse health effects (Bhupathiraju and Hu, 2016; Piqueras et al., 2021; Powell-Wiley et al., 2021). In Table 6-6, abdominal obesity is defined as a waist circumference greater than 102 cm (40 in.) for men or greater than 88 cm (35 in.) for women. In the United States, 31 to 63 percent of adult males and 51 to 80 percent of females have abdominal obesity. In Canada, the prevalence of abdominal obesity is 19 to 48 percent for males and 31 to 68 percent for females.

Data on the prevalence of obesity by race and ethnicity are also available for U.S. and Canadian populations (See Supplemental Appendix Tables Y-14, Y-15, Y-16, and Y-17). For U.S. males 19 years and older, the prevalence of obesity is 14.1 percent for non-Hispanic Asians, 38.3 percent for non-Hispanic Blacks, 41.4 percent for non-Hispanic Whites, and 44.2 percent for Hispanic adults. For U.S. females 19 years and older, prevalence of obesity is 16.0 percent for non-Hispanic Asians, 39.7 percent for non-Hispanic Whites, 46.3 percent for Hispanic adults, and 55.7 percent for non-Hispanic Blacks. For Canadians, because of small sample sizes for race/ethnicity groups, the available prevalence data were limited to two groups: *White* and *other or multiple origins*. For Canadian males 19 years and older, 30.6 percent of Whites and 19.1 percent of adults of other or multiple origins have obesity. For Canadian females 19 years and older, 28.2 percent of Whites have obesity compared to 19.5 percent of adults of other or multiple origins. For both U.S. and Canadian males and females, the prevalence of abdominal obesity is generally similar to or higher than prevalence of obesity. These data are important for assessing the energy balance/imbalance status of EER life-stage groups in these two countries and for providing useful population prevalence and reference data for clinical, educational, public health, and research applications.

Body Measurements

The concurrent availability of data on both prevalence of various BMI categories and prevalence of abdominal obesity in representative U.S. and Canadian populations suggest that the prevalence of abdominal obesity may differ from that of overweight and obesity. Thus, use of measures of visceral adiposity could help minimize misclassification of persons whose body weight is not affected by abdominal adiposity or persons of normal weight who have excessive abdominal obesity. This would result in more accurate identification of individuals at risk of adverse health outcomes associated with abdominal obesity (Piqueras et al., 2021; Shuster et al., 2012). Summary data for several anthropometric body composition measurements—waist circumference, sagittal abdominal diameter, and waist–

TABLE 6-6 Prevalence of Normal Weight, Overweight, Obesity, and Abdominal Obesity, U.S. and Canadian Adults

Life-Stage Group	United States	Canada	United States	Canada	United States	Canada	United States	Canada
	% Normal (SE)		% Overweight (SE)		% Obesity (SE)		% Abdominal Obesity (SE)	
Males								
19–30 years	37.3 (2.2)	47.6 (2.7)*	26.9 (2.3)	31.1 (2.1)	32.5 (3.1)	19.0 (2.0)*	30.6 (2.9)	18.8 (2.5)*
31–50 years	18.1 (1.4)	30.0 (1.9)*	37.6 (2.0)	40.0 (1.9)	43.7 (2.2)	29.3 (2.2)*	48.3 (2.2)	31.3 (2.2)*
51–70 years	19.7 (1.9)	24.4 (1.5)	36.9 (2.0)	45.2 (1.8)*	42.6 (2.3)	30.2 (1.8)*	57.3 (2.3)	44.0 (1.9)*
> 70 years	21.0 (1.7)	20.2 (2.5)	41.4 (2.0)	50.9 (3.3)*	36.7 (2.7)	28.4 (2.8)*	62.7 (2.7)	47.8 (3.1)*
19+ years	23.2 (1.1)	31.1 (1.0)*	35.4 (1.2)	40.6 (1.2)*	40.2 (1.8)	27.4 (1.3)*	48.7 (1.7)	34.1 (1.4)*
Females								
19–30 years	38.8 (2.6)	52.6 (3.1)*	23.4 (1.9)	23.3 (2.4)	34.1 (2.3)	18.7 (2.3)*	50.9 (2.3)	31.4 (2.9)*
31–50 years	28.4 (2.0)	42.7 (2.2)*	27.1 (1.6)	29.1 (1.8)	43.4 (1.6)	25.1 (1.9)*	67.9 (1.7)	46.2 (2.4)*
51–70 years	24.8 (1.6)	35.4 (1.9)*	28.2 (1.8)	32.4 (1.6)	45.4 (2.1)	30.7 (1.8)*	76.3 (2.1)	60.4 (1.8)*
> 70 years	25.8 (1.8)	28.0 (3.0)	34.3 (1.7)	44.6 (3.3)*	39.1 (1.8)	26.0 (2.6)*	80.1 (1.9)	68.5 (2.9)*
19+ years	28.8 (1.2)	41.1 (1.6)*	27.8 (0.7)	30.2 (1.1)	41.7 (1.4)	25.9 (1.4)*	69.1 (1.4)	49.9 (1.7)*

NOTES: SE = standard error. Prevalence values in table will not add to 100% because the underweight category has not been included in the table (due to low prevalence). BMI categories: underweight < 18.5; normal weight 18.5 to < 25; overweight 25.0 to < 30.0; obese ≥ 30.0. Abdominal obesity: waist circumference > 102 cm for men and > 88 cm for women. Pregnant and lactating women excluded from NHANES; pregnant women excluded from CHMS.

*Statistically significant difference between U.S. and Canadian life-stage groups using *Z*-statistic; *Z*-score > 1.96 significant at $p < .05$

SOURCE: From Appendix Tables L-11 and L-12. See Supplemental Appendix Y for expanded tables.

hip ratio—for U.S. and Canadian children and adults are summarized in Tables 6-7 and 6-8, respectively.[6]

Waist circumference is a measurement taken around the abdomen at the level of the umbilicus (Piqueras et al., 2021). For adult males, values of less than 94 cm (37 in.) have been suggested as low risk and values greater than 102 cm (40 in.) as substantially increased risk (WHO, 2011). Only men 19 to 30 years of age in both the United States and Canada have mean values close to or less than 94 cm (37 in.) (Table 6-8). Mean values for all U.S. males not 19 to 30 years and for Canadian males older than 70 years are in the substantially increased risk category. Most Canadian males are in the increased risk category (94–102 cm [37–40 in.]). For adult females, values less than 80 cm (31 in.) are described as low risk (WHO, 2011). None of the female life-stage groups in the United States or Canada have a mean value below this cutoff. For adult females, values greater than 88 cm (35 in.) represent substantially increased risk. Mean values among all U.S. and most Canadian women are above this cutoff.

Sagittal abdominal diameter (SAD) was measured in NHANES (see description in Appendix K). Criteria for interpreting these values are not yet available, but they provide comparative information for life-stage groups among BMI, waist circumference, and waist–hip ratio measurements. Tables 6-7 and 6-8 provide estimates of the average SAD for U.S. children and adults.

Waist–hip ratio is an indicator of visceral fat. It is the ratio of the circumference of the waist divided by the circumference of the hips (Piqueras et al., 2021). Higher ratios indicate more fat around the waist. Waist–hip ratio has a strong correlation to type 2 diabetes mellitus (Nicolo et al., 2019). WHO guidelines suggest that for men, moderate risk of obesity-related health outcomes is associated with a waist–hip ratio of 0.96–1.0 and high risk with a ratio equal to or greater than 1.0 (Piqueras et al., 2021). Most of the age groups for adult men have average ratios within the moderate to high-risk ranges, with slightly higher ratios for U.S. than for Canadian men. For women, moderate risk is defined as a waist–hip ratio of 0.81 to 0.85 and high risk as equal to or greater than 0.86. All averages for U.S. and Canadian women are in moderate to high-risk categories, with slightly higher ratios for U.S. than for Canadian women.

Mean BMI values by race/ethnicity for U.S. males 19 years and older are 26.1 for non-Hispanic Asians, 29.1 for non-Hispanic Blacks, 29.4 for

[6] More detailed data on distributions, comparisons among different types of anthropometric variables, and race/ethnicity are available in Appendix L and Supplemental Appendix Y.

non-Hispanic Whites, and 30.1 for Hispanic adults. For U.S. females 19 years and older, mean BMI values are 25.1 for non-Hispanic Asians, 29.4 for non-Hispanic Whites, 30.6 for Hispanic adults, and 32.3 for non-Hispanic Blacks. Mean BMI values for Canadians 19 years and older are 28.0 for White males and 26.8 for males of other or multiple origins, and 27.6 for White females and 25.9 for females of other or multiple origins (see Supplemental Appendix Tables Y-42, Y-48, Y-63, and Y-69 and Supplemental Appendix Y for the expanded data tables).

Mean waist circumference by race/ethnicity for U.S. males 19 years and older is 93.1 cm (37 in.) for non-Hispanic Asians, 98.9 cm (39 in.) for non-Hispanic Blacks, 102.1 cm (40 in.) for Hispanic adults, and 104.0 cm (41 in.) for non-Hispanic Whites. For U.S. females 19 years and older, mean waist circumference is 86.2 cm (34 in.) for non-Hispanic Asians, 98.5 cm (39 in.) for non-Hispanic Whites, 98.6 cm (39 in.) for Hispanic adults, and 102.3 cm (40 in.) for non-Hispanic Blacks. For Canadians 19 years of age, mean waist circumference values are 99.2 cm (39 in.) for White males and 93.6 cm (37 in.) for males of other or multiple origins, and 92.1 cm (36 in.) for White females and 86.8 cm (34 in.) for females of other or multiple origins (see Supplemental Appendix Tables Y-46, Y-51, Y-66, and Y-72).

Dual-Energy X-Ray Absorptiometry Summaries

Dual-energy x-ray absorptiometry (DXA) is a low-dose radiation technique that can provide several measures of adiposity in clinical settings (Messina et al., 2020), although consensus is lacking in terms of interpretive criteria for most of these measures. DXA measures of adiposity that are available from NHANES indicate that total body fat mass, percent body fat, and fat mass index are higher in U.S. females than in U.S. males for all life-stage groups (Table 6-9, Appendix Tables L-13 and L-14, and Supplemental Appendix Tables Y-87 to Y-94). The mean percent body fat for adult males and females exceeds the WHO definition of obesity, which is greater than 25 percent body fat for White men and greater than 35 percent body fat for White women (Piqueras et al., 2021). Visceral adipose tissue—the hormonally active component of total fat—is higher in adult females than in adult males.

DXA measures from NHANES for race/ethnicity groups (see Supplemental Appendix Tables Y-93 and Y-94) indicate that mean percent body fat for U.S. adult males aged 19 to 59 years is 24.8 for non-Hispanic Blacks, 27.0 for non-Hispanic Whites, 27.4 for non-Hispanic Asians, and 28.3 for Hispanic adults. Mean percent body fat for U.S. adult females aged 19 to 59 years is 36.8 for non-Hispanic Asians, 38.3 for non-Hispanic Whites, 38.9 for non-Hispanic Blacks, and 40.0 for Hispanic adults. Mean

TABLE 6-7 Anthropometric Body Composition Measurements, U.S. and Canadian Children, 3–18 Years of Age

Age	BMI Mean (SE)		Waist Circumference (cm) Mean (SE)		Average Sagittal Abdominal Diameter (cm) Mean (SE)		Waist–Hip Ratio Mean (SE)	
Life-Stage Group	United States	Canada	United States	Canada	United States	Canada	United States	Canada
Males								
3 years	16.8 (0.2)	16.2 (0.2)*	51.3 (0.8)	49.9 (0.3)	---	---	---	0.91 (0.01)
4–8 years	17.1 (0.1)	16.2 (0.1)*	58.1 (0.4)	55.2 (0.4)*	---	---	---	0.87 (0.00)
9–13 years	20.6 (0.2)	19.2 (0.1)*	72.8 (0.6)	68.4 (0.4)*	16.3 (0.2)	---	---	0.85 (0.00)
14–18 years	24.0 (0.3)	23.7 (0.4)	83.4 (0.8)	82.0 (1.1)	18.5 (0.3)	---	0.86 (0.01)	0.84 (0.00)*
Females								
3 years	16.2 (0.1)	16.2 (0.2)	50.3 (0.3)	50.4 (0.4)	---	---	---	0.91 (0.01)
4–8 years	17.1 (0.1)	16.3 (0.1)*	57.8 (0.3)	55.4 (0.3)*	---	---		0.88 (0.00)
9–13 years	20.7 (0.2)	19.2 (0.2)*	72.5 (0.5)	67.5 (0.6)*	16.2 (0.2)	---	---	0.83 (0.00)
14–18 years	24.9 (0.3)	22.8 (0.2)*	82.5 (0.7)	77.1 (0.6)*	18.4 (0.2)	---	0.83 (0.01)	0.81 (0.00)*

NOTES: BMI = body mass index; cm = centimeter; kg = kilogram; m = meter; SE = standard error. This table does not include 2-year-old children because Canada has no data for this age group. The Canadian surveys did not present data on average sagittal abdominal diameter. Pregnant and lactating adolescents are excluded from NHANES; pregnant adolescents are excluded from CHMS.

*Statistically significant difference between U.S. and Canadian life-stage groups.

SOURCES: From Appendix Tables L-1, L-2, L-5, L-6, and Supplemental Appendix Tables Y-1 and Y-2.

TABLE 6-8 Anthropometric Body Composition Measurements, U.S. and Canadian Adults, 19 Years of Age and Older

	BMI Mean (SE)		Waist Circumference (cm) Mean (SE)		Average Sagittal Abdominal Diameter (cm) Mean (SE)		Waist–Hip Ratio Mean (SE)	
Life-Stage Group	United States	Canada	United States	Canada	United States	Canada	United States	Canada
Males								
19–30 years	27.8 (0.4)	26.1 (0.3)*	94.5 (1.0)	90.5 (1.0)*	21.4 (0.2)	---	0.91 (0.01)	0.88 (0.01)*
31–50 years	30.2 (0.3)	27.8 (0.3)*	103.5 (0.6)	97.2 (0.7)*	23.6 (0.3)	---	0.97 (0.00)	0.94 (0.00)
51–70 years	29.7 (0.2)	28.4 (0.2)*	106.0 (0.7)	101.5 (0.5*	24.2 (0.3)	---	1.01 (0.01)	0.98 (0.00)*
> 70 years	28.7 (0.2)	28.2 (0.2)	106.4 (0.7)	103.1 (0.8)*	24.4 (0.3)	---	1.01 (0.00)	1.00 (0.01)
19+ years	29.4 (0.2)	27.7 (0.1)*	102.6 (0.5)	97.6 (0.4)*	23.4 (0.2)	---	0.97 (0.00)	0.95 (0.00)
Females								
19–30 years	28.3 (0.4)	25.6 (0.4)*	92.5 (0.9)	84.6 (1.0)*	20.2 (0.2)	---	0.86 (0.01)	0.83 (0.01)*
31–50 years	30.5 (0.3)	27.1 (0.3)*	98.9 (0.8)	90.1 (0.9)*	21.9 (0.2)	---	0.88 (0.00)	0.87 (0.00)
51–70 years	30.3 (0.3)	28.0 (0.3)*	100.7 (0.8)	94.1 (0.6)*	23.2 (0.3)	---	0.91 (0.01)	0.89 (0.00)*
> 70 years	29.0 (0.3)	27.7 (0.3)*	100.2 (0.6)	94.2 (0.7)*	22.8 (0.3)	---	0.93 (0.00)	0.89 (0.00)
19+ years	29.8 (0.2)	27.1 (0.2)*	98.3 (0.6)	90.7 (0.6)*	22.1 (0.2)	---	0.89 (0.00)	0.87 (0.00)

NOTES: BMI = body mass index; cm = centimeter; kg = kilogram; m = meter; SE = standard error. The Canadian surveys do not have data on average sagittal abdominal diameter. Pregnant and lactating women excluded from NHANES; pregnant women excluded from the Canadian Health Measures Survey.

*Statistically significant difference between U.S. and Canadian life-stage groups.

SOURCES: From Appendix Tables L-3, L-4, L-7, and L-8. See Supplemental Appendix Y for the expanded set of tables.

TABLE 6-9 DXA Body Composition Summary Statistics, Ages 8–59 Years, United States

Age (years)	Total Body Fat Mass (g) Mean (SE)		Percent Body Fat (%) Mean (SE)		Lean Mass Index Mean (SE)		Fat Mass Index Mean (SE)		Visceral Adipose Tissue (g) Mean (SE)	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
8	9.5 (0.4)	10.9 (0.5)*	28.1 (0.6)	32.8 (0.7)*	12.8 (0.1)	12.3 (0.2)*	---	---	162.9 (4.0)	133.6 (10.7)
9–13	14.4 (0.4)	15.6 (0.4)*	29.0 (0.4)	32.4 (0.3)*	14.4 (0.1)	13.7 (0.1)*	---	---	176.9 (2.2)	169.4 (5.8)
14–18	17.6 (0.6)	23.2 (0.5)*	23.5 (0.5)	34.7 (0.4)*	17.8 (0.2)	15.8 (0.1)*	---	---	198.4 (2.6)	218.2 (8.6)
19–30	22.5 (0.5)	28.0 (0.9)*	25.5 (0.3)	36.7 (0.5)*	20.1 (0.2)	17.2 (0.2)*	7.4 (0.2)	10.6 (0.3)*	238.5 (4.4)	322.4 (12.2)
31–50	25.9 (0.4)	31.8 (0.5)*	27.8 (0.2)	38.9 (0.3)*	21.1 (0.1)	18.0 (0.1)*	8.5 (0.1)	12.1 (0.2)*	331.6 (10.8)	488.0 (13.1)
51–59	25.2 (0.6)	31.8 (0.7)*	27.9 (0.4)	40.3 (0.3)*	20.8 (0.2)	17.4 (0.2)*	8.3 (0.2)	12.2 (0.3)*	445.0 (25.3)	596.8 (18.8)
19–59	24.7 (0.3)	30.7 (0.5)*	27.1 (0.2)	38.6 (0.3)*	20.8 (0.1)	17.6 (0.1)*	8.1 (0.1)	11.7 (0.2)*	310.0 (8.3)	470.1 (11.0)

NOTES: DXA = dual-energy x-ray absorptiometry; g = grams; kg = kilogram; m = meter; SE = standard error. DXA results not available from CHMS. Fat mass index calculated as fat mass/height^2 and lean mass index as lean mass (including bone mineral content)/height^2. No statistical test results are available to compare male and female data for visceral adipose tissue. Pregnant and lactating women excluded.

*Statistically significant difference between U.S. males and females.

SOURCE: NHANES (see Appendix Tables L-13 and L-14). See Supplemental Appendix Tables Y-87 to Y-94 for the expanded set of tables.

visceral adipose tissue for U.S. adult males is 408.3 g (14 oz) for non-Hispanic Blacks, 471.5 g (17 oz) for non-Hispanic Asians, 565.4 g (20 oz) for Hispanic adults, and 565.8 g (20 oz) for non-Hispanic Whites. Similar data for U.S. adult females are 370.5 g (13 oz) for non-Hispanic Asians, 417.3 g (15 oz) for non-Hispanic Blacks, 474.8 g (17 oz) for non-Hispanic Whites, and 516.2 g (18 oz) for Hispanic adults.

The anthropometric and DXA data in conjunction with BMI data provide useful information on the weight status of U.S. and Canadian populations and reference values for multiple research, clinical, and policy applications. Clearly, more research is needed on interpretive criteria for the different indices and, in some cases, for race/ethnicity, age/sex, and other subgroups. Identifying the best indicator or combination of indicators for predicting adverse health outcomes associated with energy intake imbalances and the risk of specific chronic diseases is also needed.

Indicators of Physical Activity

The 2018 *Physical Activity Guidelines for Americans* recommends that children ages 6 through 17 years get 60 minutes per day of moderate-to-vigorous physical activity (MVPA), to include muscle- and bone-strengthening activities as well as aerobic activity (DHHS, 2018). The target for adults is 150 to 300 minutes per week of moderate-intensity physical activity or an equivalent mix of moderate- and vigorous-intensity aerobic activity as well as muscle-strengthening activities at least twice per week. Data from the National Health Interview Survey and the Youth Risk Behavioral Surveillance System was used to track national health objectives,[7] and they showed that in 2020, 25.2 percent of adults met the combined muscle-strengthening and aerobic recommendations, while 47.9 percent met the aerobic activity recommendation alone. Prevalence for males exceeded that for females for the combined (29.0 vs. 21.5 percent) and aerobic measures (52.2 vs. 43.8 percent). In 2019, only 16.5 percent of students in grades 9 through 12 met the combined recommendation for youth. Adolescent males were more likely than females to report meeting the recommendation (23.1 vs. 10.1 percent). As was the case for adults, prevalence was higher for meeting only the aerobic recommendation (23.2 percent), with adolescent males having higher prevalence than adolescent females (30.9 vs. 15.4 percent).

Data from NHANES 2011–2014 collected with wrist-worn accelerometers provide a measure of total physical activity across ages 3 to 80

[7] https://health.gov/healthypeople/objectives-and-data/browse-objectives/physical-activity (accessed February 8, 2023).

years and older (Belcher et al., 2021). The Monitor Independent Motion Summary (MIMS) units are not translated into physical activity intensity or energy expenditure, but they show how movement activity varies across age and sex within the United States. Among youth, values for males and females were similar for ages 3 to 5 years, with activity increasing from age 3 to 6 years then declining until age 17 to 18 years. Beginning at age 6 years among youth and among adults, movement activity was generally higher among females than among males. Median values peaked at age 20 years for males and 36 years for females and then decreased with increasing age.

Data from CHMS for 2018 and 2019 indicate that 49 percent of Canadian adults are meeting the 150 minutes per week of moderate to vigorous exercise recommendation with an average of 27 minutes of MVPA per day. The percent meeting the requirement declines with advancing age. Children and youth had a slightly lower percentage (44 percent) of meeting the Canadian physical activity target recommended in the Canadian 24-hour Movement Guidelines during the same time period. These estimates were all measured using a physical activity monitor (Statistics Canada, 2021).

When data from devices are used to assess compliance with recommended amounts of aerobic physical activity, the estimates tend to be lower, but as noted, depend upon criteria used to define moderate- or vigorous-intensity physical activity. Devices generally cannot measure muscle-strengthening physical activity.

A systematic review by Foulds et al. (2013) investigated the question of whether Native American populations in the United States and Canada attained recommended physical activity levels. The review also compared current and past activity levels and assessed the effect of exercise training programs on health outcomes in the population. From among more than 100,000 participants, adults in the population had an average physical activity level (PAL) of 1.48, while children, at age 5 years, had a PAL of 1.42. The study concluded that physical activity levels among Native American adults have decreased since 1990 and that a greater proportion of adults reported being inactive.

FINDINGS AND CONCLUSIONS

Assessment of Energy Intake and Expenditure

Findings

> The committee finds that although it is possible to characterize usual energy intakes using statistical methods to account for random error,

self-reported energy intakes for both U.S. and Canadian life-stage groups are still prone to systematic measurement error. In the absence of self-report, tracking indicators of long-term energy intakes that exceed the requirements for maintenance of a healthy weight are used rather than tracking energy intakes for the population.

Conclusions

From the evidence reviewed, the committee concludes that research efforts to improve the accuracy of dietary intake data are needed and that users of these data need to be aware of significant underreporting bias. Alternative approaches to self-report are also needed to assess usual energy intakes in the U.S. and Canadian populations. Additionally, new methods are needed to assess dietary intake of children.

Assessment of Physical Activity

Findings

The committee finds disagreement between measures of physical activity and energy expenditure. This indicates that the terms are not interchangeable. Physical activity is movement, whereas energy expenditure reflects age, sex, body mass, and economy of movement. Further, the committee found substantial discrepancies and low correlations between commonly used indirect and direct methods of assessing physical activity. Total physical activity is a function of movement type and the intensity, duration, and frequency with which it is performed. Methods of assessing physical activity are not interchangeable, as they frequently measure different properties or components.

The committee's overall examination of self-report measures finds that the vast majority of correlation coefficients are considered poor to moderate. This suggests that most self-report measures may be valid for classifying individuals' behaviors for the type and intensity, but less useful for estimating total energy expenditure. For device-based measures, Pearson's correlations ranged from 0.58 to 0.88 for accelerometer-based predictions compared to room and indirect calorimetry, with large variation at the individual level. Wrist-worn and arm-worn research-grade devices were more accurate than commercial devices for estimates of TEE. The committee notes that such devices do not guarantee superior accuracy.

Conclusions

Although no perfect tool exists for examining physical activity, the committee concludes that when examining physical activity in adults in free-living environments, researchers should incorporate appropriate objective measures that are specific to the behaviors of interest. Additionally, although the methodological effectiveness of physical activity measures is well documented, the committee concludes that development of an appropriate, consistent approach to conducting research and reporting findings is necessary to enable cross-instrument findings.

Indicators of Body Weight and Adiposity

Findings

The committee finds that the available NHANES and CHMS data provide a wealth of information on the indicators of long-term energy intakes that exceed the intakes needed to maintain healthy body weight (i.e., weight and body composition status of U.S. and Canadian population groups)—for both EER life-stage groups and race/ethnicity subgroups. Appendix L and Supplemental Appendix Y provide data on both anthropometric and DXA results stratified by weight category, with further stratification for race/ethnicity groups using the DRI life-stage groupings.

Conclusions

The committee concludes that the prevalence of overweight and obesity in the U.S. and Canadian populations is of concern, and that the prevalence is somewhat higher for the U.S. than for Canadian populations. Further, while anthropometric and DXA data require more research to confirm interpretive criteria and to assess their validity as predictors of risk of adverse health outcomes, the reference values suggest that these data could help identify individuals at the greatest risk of energy intakes that exceed intakes required to maintain healthy body weights. Differences related to ancestry support the need for tailored approaches to help these groups maintain or achieve healthy body weights. In total, these results characterize and underscore the seriousness of public health concerns related to overweight and obesity among U.S. and Canadian population groups.

The survey data for U.S. and Canadian populations show differences in the prevalence of high BMI/obesity and high waist circumference by sex and by self-reported race/ethnicity. The committee concludes that these differences *may be a consequence of health disparities, and thus, support the need to tailor programs and interventions to the subgroups of the populations served.*

REFERENCES

Adamo, K. B., S. A. Prince, A. C. Tricco, S. Connor-Gorber, and M. Tremblay. 2009. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity* 4(1):2-27.

Bailey, R. L. 2021. Overview of dietary assessment methods for measuring intakes of foods, beverages, and dietary supplements in research studies. *Current Opinion in Biotechnology* 70:91-96.

Basiotis, P. P., S. O. Welsh, F. J. Cronin, J. L. Kelsay, and W. Mertz. 1987. Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *Journal of Nutrition* 117(9):1638-1641.

Belcher, B. R., D. L. Wolff-Hughes, E. E. Dooley, J. Staudenmayer, D. Berrigan, M. S. Eberhardt, and R. P. Troiano. 2021. US population-referenced percentiles for wrist-worn accelerometer-derived activity. *Medicine and Science in Sports and Exercise* 53(11):2455-2464.

Bhupathiraju, S. N., and F. B. Hu. 2016. Epidemiology of obesity and diabetes and their cardiovascular complications. *Circulation Research* 118(11):1723-1735.

Boushey, C. J., M. Spoden, F. M. Zhu, E. J. Delp, and D. A. Kerr. 2017. New mobile methods for dietary assessment: Review of image-assisted and image-based dietary assessment methods. *Proceedings of the Nutrition Society* 76(3):283-294.

Burrows, T. L., R. J. Martin, and C. E. Collins. 2010. A systematic review of the validity of dietary assessment methods in children when compared with the method of doubly labeled water. *Journal of the American Dietetic Association* 110(10):1501-1510.

Burrows, T. L., Y. Y. Ho, M. E. Rollo, and C. E. Collins. 2019. Validity of dietary assessment methods when compared to the method of doubly labeled water: A systematic review in adults. *Frontiers in Endocrinology* 10.

Burrows, T., S. Goldman, and M. Rollo. 2020. A systematic review of the validity of dietary assessment methods in children when compared with the method of doubly labelled water. *European Journal of Clinical Nutrition* 74(5):669-681.

Capling, L., K. L. Beck, J. A. Gifford, G. Slater, V. M. Flood, and H. O'Connor. 2017. Validity of dietary assessment in athletes: A systematic review. *Nutrients* 9(12).

CDC (Centers for Disease Control and Prevention). 2022. *Adult obesity facts*. https://www.cdc.gov/obesity/data/adult.html. (accessed November 24, 2022).

Crouter, S. E., P. R. Hibbing, and S. R. LaMunion. In press. Physical activity assessment. In *Health professional's guide to obesity and weight management*. Edited by H. A. Raynor and L. Gigliotti. Chicago, IL: Academy of Nutrition and Dietetics.

DHHS (U.S. Department of Health and Human Services). 2018. *Physical activity guidelines for Americans,* 2nd ed. Washington, DC: U.S. Department of Health and Human Services.

Dodd, K. W., P. M. Guenther, L. S. Freedman, A. F. Subar, V. Kipnis, D. Midthune, J. A. Tooze, and S. M. Krebs-Smith. 2006. Statistical methods for estimating usual intake of nutrients and foods: A review of the theory. *Journal of the American Dietetic Association* 106(10):1640-1650.

Dowd, K. P., R. Szeklicki, M. A. Minetto, M. H. Murphy, A. Polito, E. Ghigo, H. van der Ploeg, U. Ekelund, J. Maciaszek, R. Stemplewski, M. Tomczak, and A. E. Donnelly. 2018. A systematic literature review of reviews on techniques for physical activity measurement in adults: A DEDIPAC study. *International Journal of Behavioral Nutrition and Physical Activity* 15(1):15.

Dwyer, J. T., J. Gardner, K. Halvorsen, E. A. Krall, A. Cohen, and I. Valadian. 1989. Memory of food intake in the distant past. *American Journal of Epidemiology* 130(5):1033-1046.

Foulds, H. J. A., D. E. R. Warburton, and S. S. D. Bredin. 2013. A systematic review of physical activity levels in Native American populations in Canada and the United States in the last 50 years. *Obesity Reviews* 14(7):593-603.

Gemming, L., J. Utter, and C. Ni Mhurchu. 2015. Image-assisted dietary assessment: A systematic review of the evidence. *Journal of the Academy of Nutrition and Dietetics* 115(1):64-77.

Gibson, R. S. 1990. *Principles of nutritional assessment*. New York: Oxford University.

Helmerhorst, H. J., S. Brage, J. Warren, H. Besson, and U. Ekelund. 2012. A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. *International Journal of Behavioral Nutrition & Physical Activity* 9:103.

Ho, D. K. N., S. H. Tseng, M. C. Wu, C. K. Shih, A. P. Atika, Y. C. Chen, and J. S. Chang. 2020. Validity of image-based dietary assessment methods: A systematic review and meta-analysis. *Clinical Nutrition* 39(10):2945-2959.

Kirkpatrick, S. I., A. F. Subar, and J. A. Tooze. 2018. Statistical approaches to mitigate measurement error in dietary intake data collected using 24-hour recalls and food records/diaries. In *Advances in the assessment of dietary intake*, edited by D. E. Schoeller and M. Westerterp. Boca Raton, FL: CRC Press.

Livingstone, M. B., and P. J. Robson. 2000. Measurement of dietary intake in children. *Proceedings of the Nutrition Society* 59(2):279-293.

Livingstone, M. B., P. J. Robson, and J. M. Wallace. 2004. Issues in dietary intake assessment of children and adolescents. *British Journal of Nutrition* 92(Suppl 2):S213-S222.

Macfarlane, D. J. 2017. Open-circuit respirometry: A historical review of portable gas analysis systems. *European Journal of Applied Physiology* 117(12):2369-2386.

McClung, H. L., L. T. Ptomey, R. P. Shook, A. Aggarwal, A. M. Gorczyca, E. S. Sazonov, K. Becofsky, R. Weiss, and S. K. Das. 2018. Dietary intake and physical activity assessment: Current tools, techniques, and technologies for use in adult populations. *American Journal of Preventive Medicine* 55(4):e93-e104.

Messina, C., D. Albano, S. Gitto, L. Tofanelli, A. Bazzocchi, F. M. Ulivieri, G. Guglielmi, and L. M. Sconfienza. 2020. Body composition with dual energy x-ray absorptiometry: From basics to new tools. *Quantitative Imaging in Medical Surgery* 10(8):1687-1698.

Nicolo, M. L., C. W. Compher, P. A. Shewokis, J. I. Boullata, D. Sukumar, S. A. Smith, and S. L. Volpe. 2019. Anthropometric predictors of hemoglobin A1c among adults: NHANES 2003 to 2004 and 2013 to 2014. *Translational Journal of the American College of Sports Medicine* 4(21):242-247.

NRC (National Research Council). 1986. *Nutrient adequacy*. Washington, DC: National Academy Press.

Nusser, S. M., A. L. Carriquiry, K. W. Dodd, and W. A. Fuller. 1996. A semiparametric transformation approach to estimating usual daily intake distributions. *Journal of the American Statistical Association* 91(436):1440-1449.

O'Driscoll, R., J. Turicchi, K. Beaulieu, S. Scott, J. Matu, K. Deighton, G. Finlayson, and J. Stubbs. 2020. How well do activity monitors estimate energy expenditure? A systematic review and meta-analysis of the validity of current technologies. *British Journal of Sports Medicine* 54(6):332-340.

Overstreet, B. S., D. R. Bassett, Jr., S. E. Crouter, B. C. Rider, and B. B. Parr. 2017. Portable open-circuit spirometry systems. *Journal of Sports Medicine and Physical Fitness* 57(3):227-237.

Piqueras, P., A. Ballester, J. V. Dura-Gil, S. Martinez-Hervas, J. Redon, and J. T. Real. 2021. Anthropometric indicators as a tool for diagnosis of obesity and other health risk factors: A literature review. *Frontiers in Psychology* 12:631179.

Powell-Wiley, T. M., P. Poirier, L. E. Burke, J. P. Despres, P. Gordon-Larsen, C. J. Lavie, S. A. Lear, C. E. Ndumele, I. J. Neeland, P. Sanders, M. P. St-Onge, on behalf of the American Heart Association Council on Lifestyle and Cardiometabolic Health, Council on Cardiovascular and Stroke Nursing, Council on Clinical Cardiology, Council on Epidemiology and Prevention, and Stroke Council. 2021. Obesity and cardiovascular disease: A scientific statement from the American Heart Association. *Circulation* 143(21):e984-e1010.

Schoeller, D. A., and E. van Santen. 1982. Measurement of energy expenditure in humans by doubly labeled water method. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology* 53(4):955-959.

Schoffelen, P. F. M., M. den Hoed, E. van Breda, and G. Plasqui. 2019. Test-retest variability of VO2max using total-capture indirect calorimetry reveals linear relationship of VO2 and power. *Scandinavian Journal of Medicine and Science in Sports* 29(2):213-222.

Shuster, A., M. Patlas, J. H. Pinthus, and M. Mourtzakis. 2012. The clinical importance of visceral adiposity: A critical review of methods for visceral adipose tissue analysis. *British Journal of Radiology* 85(1009):1-10.

Souverein, O. W., A. L. Dekkers, A. Geelen, J. Haubrock, J. H. de Vries, M. C. Ocke, U. Harttig, H. Boeing, P. van 't Veer, and E. Consortium. 2011. Comparing four methods to estimate usual intake distributions. *European Journal of Clinical Nutrition* 65(Suppl 1):S92-S101.

Speakman, J. R. 1998. The history and theory of the doubly labeled water technique. *American Journal of Clinical Nutrition* 68(4):932S-938S.

Statistics Canada. 2019. *Health fact sheets: Overweight and obese adults, 2018*. https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/article/00005-eng.htm (accessed September 30, 2022).

Statistics Canada. 2021. *Half of Canadian adults meet the new physical activity recommendation* https://www150.statcan.gc.ca/n1/daily-quotidien/210901/dq210901c-eng.htm (accessed November 21, 2022).

Strath, S. J., L. A. Kaminsky, B. E. Ainsworth, U. Ekelund, P. S. Freedson, R. A. Gary, C. R. Richardson, D. T. Smith, A. M. Swartz, on behalf of the American Heart Association Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health and Cardiovascular, Exercise, Cardiac Rehabilitation and Prevention Committee of the Council on Clinical Cardiology, and Council on Cardiovascular and Stroke Nursing. 2013. Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. *Circulation* 128(20):2259-2279.

Subar, A. F., K. W. Dodd, P. M. Guenther, V. Kipnis, D. Midthune, M. McDowell, J. A. Tooze, L. S. Freedman, and S. M. Krebs-Smith. 2006. The food propensity questionnaire: Concept, development, and validation for use as a covariate in a model to estimate usual food intake. *Journal of the American Dietetic Association* 106(10):1556-1563.

Sylvia, L. G., E. E. Bernstein, J. L. Hubbard, L. Keating, and E. J. Anderson. 2014. Practical guide to measuring physical activity. *Journal of the Academy of Nutrition and Dietetics* 114(2):199-208.

Thompson, F. E., S. I. Kirkpatrick, A. F. Subar, J. Reedy, T. E. Schap, M. M. Wilson, and S. M. Krebs-Smith. 2015. The National Cancer Institute's dietary assessment primer: A resource for diet research. *Journal of the Academy of Nutrition and Dietetics* 115(12):1986-1995.

Tooze, J. A., D. Midthune, K. W. Dodd, L. S. Freedman, S. M. Krebs-Smith, A. F. Subar, P. M. Guenther, R. J. Carroll, and V. Kipnis. 2006. A new statistical method for estimating the usual intake of episodically consumed foods with application to their distribution. *Journal of the American Dietetic Association* 106(10):1575-1587.

Tooze, J. A., V. Kipnis, D. W. Buckman, R. J. Carroll, L. S. Freedman, P. M. Guenther, S. M. Krebs-Smith, A. F. Subar, and K. W. Dodd. 2010. A mixed-effects model approach for estimating the distribution of usual intake of nutrients: The NCI method. *Statistics in Medicine* 29(27):2857-2868.

Tudor-Locke, C., J. E. Williams, J. P. Reis, and D. Pluto. 2002. Utility of pedometers for assessing physical activity: Convergent validity. *Sports Medicine* 32(12):795-808.

Tugault-Lafleur, C. N., J. L. Black, and S. I. Barr. 2017. A systematic review of methods to assess children's diets in the school context. *Advances in Nutrition* 8(1):63-79.

Wehling, H., and J. Lusher. 2019. People with a body mass index 30 under-report their dietary intake: A systematic review. *Journal of Health Psychology* 24(14):2042-2059.

WHO (World Health Organization). 2011. Waist circumference and waist–hip ratio: Report of a WHO expert consultation, Geneva, 8–11 December 2008. Geneva: World Health Organization.

WHO. 2021. *Obesity and overweight*. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed November 24, 2022).

7

Applications of the Dietary Reference Intakes for Energy

Dietary Reference Intakes (DRIs), including the Estimated Energy Requirement (EER), have primary applications in planning and assessing dietary intakes for both individuals and groups. The overarching goal is to achieve intakes that are adequate (i.e., that meet the requirement for a nutrient and thus prevent adverse effects of inadequacy) but not excessive (i.e., that have potential to lead to adverse effects of overconsumption). For energy, *adequacy* refers to the energy required to maintain an individual's current level of physical activity and body weight and composition (or an appropriate rate of weight gain during growth and pregnancy)—this value for energy is what is predicted by the EER equations. *Excessive* intakes of energy would result in weight gain, and *inadequate* intakes of energy would result in weight loss. Weight gain or weight loss may be desirable in some cases, but EER prediction equations are not designed for those goals.

In this chapter, the committee examines appropriate uses of the calculated energy expenditure equations to predict EERs of the general population, including individuals and groups. It then discusses the use of body weight stability and status, rather than self-reported energy intake, to assess adequacy of energy intake. Finally, the updated EERs are compared to previous values from the IOM (2002/2005) report on DRIs for macronutrients and energy.

PLANNING ENERGY INTAKES

The objective of dietary planning is to establish a diet with low risk of inadequacy and of excess. As described in IOM (2003), for most nutrients this is attained for individuals by planning a nutrient intake that meets the Recommended Dietary Allowance (RDA) for the individual's age/sex group (and therefore, meets or exceeds the requirements of 97 to 98 percent of individuals in that age/sex group) and remains below the Tolerable Upper Intake Level (UL), a point at which the risk of an adverse health effect increases beyond an acceptable level. Thus, a safe range of intake exists between the RDA and the UL, a range that is quite broad for many nutrients. For groups, the goals of an acceptably low prevalence of inadequacy and of excess are met by planning the usual intake distribution such that it has an acceptably low proportion (e.g., 2–3 percent), with usual intakes below the Estimated Average Requirement (EAR) and a minimal proportion with usual intakes above the UL.

This approach is not appropriate for energy for several reasons. First, there is no safe range of intake because energy intakes outside of requirements lead to either weight gain or loss. Accordingly, energy has neither an RDA nor a UL, which are intake values. Rather, energy has an EER equation, which was developed to predict an appropriate energy intake. Identifying an RDA for energy would be infeasible. By definition, this value would exceed the requirements of 97 to 98 percent of individuals and would lead to weight gain in those individuals. Second, whereas intakes above an individual's requirement do not lead to adverse effects (provided they are below the UL) for most other nutrients, this is not true for energy because intakes above the requirement would lead to weight gain. Third, unlike intake recommendations for most other nutrients—which apply to all individuals in an age/sex group (e.g., men aged 31–50 years)—the EER equations are specific for sex, age, height, weight, and physical activity level (PAL). Therefore, EERs for individuals within an age/sex group can vary considerably, and actual energy needs vary even among individuals of the same sex, age, height, weight, and PAL category (and thus the same EER), because some individuals will require considerably more energy than predicted by their EER and others will require less.

Therefore, planning for energy intakes of individuals and groups using the EER should be considered as a two-step process: (1) select the appropriate EER equation to use for the individual or group (this includes identifying the correct PAL category) and calculate the EER; and (2) monitor body weight over time and adjust energy intake as needed to maintain an appropriate body weight. Because a critical element in selecting the appropriate EER equation is identifying the correct PAL category, this step is described in the following section along with descriptions of the planning process for individuals and for groups.

Selecting the Appropriate Physical Activity Level Category

Perhaps the most challenging aspect of using the EER equations is selecting the appropriate PAL category, which must be done for individuals aged 3 years and above. PAL represents the ratio of total energy expenditure (TEE, as determined in doubly labeled water [DLW] studies) to measured or calculated basal energy expenditure (BEE) or resting energy expenditure (REE). As described in Chapter 5, the committee identified four PAL categories (inactive, low active, active, and very active) based on approximate quartiles of the PAL distributions among age groups of participants in DLW studies. Those with a PAL in the bottom quartile of the distribution for an age/sex group were identified as inactive, those with a PAL in the second quartile as low active, those in the third quartile as active, and those in the fourth quartile as very active. Separate equations to predict the EER were developed for each PAL category.

In this context, the four PAL categories reflect energy expenditure (kcal/d). The inactive category reflects a level of TEE covering basal metabolism, diet-induced thermogenesis (DIT), and a minimal level of physical activity required for activities of daily living. The low active, active, and very active categories reflect increasing levels of physical activity through occupational and recreational activities. Notably, the PAL categories do not correspond to the physical activity guidelines for health of Americans and Canadians (Canadian Society for Exercise Physiology, 2021; DHHS, 2018). Those guidelines recommend, for example, that adults obtain a minimum of 150 minutes of moderate-to-vigorous activity (e.g., brisk walking) or 75 minutes of vigorous activity (e.g., running) per week, as these activity levels are associated with health benefits. It is not possible to classify an individual's PAL category, however, based on whether the person meets the recommended levels of physical activity.

Under ideal circumstances, evidence would be available to show strong associations between PAL as assessed in DLW studies and outputs from more readily available methods of assessing physical activity, such as steps (from a pedometer) or self-report measures based on physical activity questionnaires. As described in Chapter 6, some studies have detected statistically significant associations, but in many cases, the correlations at the individual levels are weak or, in some cases, not significant. At present, it appears that a valid, reliable tool does not exist to enable accurate classification of an individual's PAL category.

Nonetheless, a descriptive analysis of daily activity patterns (Table 7-1) can provide guidance for classifying an individual's PAL category. Of note is that individuals in the "inactive" PAL category are not completely sedentary but are minimally active beyond what is involved in daily living and do little or no occupational physical activity. The "low active"

TABLE 7-1 Example of Daily Activities Associated with Physical Activity Level (PAL) Categories in Adults

Activities of daily living (ADL) for all activity levels	Inactive (PAL ~1.4)	Low active (PAL ~1.6)	Active (PAL ~1.75)	Very active (PAL ~2.05)
30 minutes walking; plus ~90 minutes light to moderate activity (household tasks, vacuuming, raking the lawn, etc.)	ADL only	ADL + 60–80 minutes walking (3–4 mph)	ADL + 30–50 minutes walking (3–4 mph) + 45 minutes moderate cycling + 40 minutes doubles tennis	ADL + 45 minutes moderate cycling + ~25 minutes jogging (10 min/mile) + 60 minutes doubles tennis

NOTE: ADL = activities of daily living; mph = miles per hour; PAL = physical activity level. Ranges for PAL categories: inactive: $1.0 \leq PAL < 1.53$; low active: $1.53 \leq PAL < 1.68$; active: $1.68 \leq PAL < 1.85$; very active: $1.85 \leq PAL < 2.50$.
SOURCE: Modified from Table 12-2 (IOM, 2002/2005).

category involves an additional 60 to 80 minutes of moderate intensity activity (walking), and the "active" adds 30 to 50 minutes of moderate intensity activity (walking) and 85 minutes of vigorous activity (cycling and tennis). Finally, the "very active" category entails the addition of more than 2 hours of vigorous activity (cycling, jogging, and tennis). Other activities could be substituted for those shown; the intent of the example is to provide a general indication of the amount and intensity of activity associated with each PAL category.

The examples in Table 7-1 may be most appropriate for individuals in occupations that require little physical exertion or movement, such as office work. Additional guidance that incorporates occupational activity is available from the analysis by Black et al. (1996) of 574 DLW measurements of individuals aged 2 to 95 years. They used the robust data set to examine the relationship between lifestyle activity and PAL to summarize activity associated with different PAL categories as: 1.2 equates to chairbound or bedbound; 1.4 equates to sitting without moving and with little or no strenuous leisure activity; 1.6 to 1.7 includes discretion to move but little or no strenuous leisure activity; 1.8 to 1.9 equates to standing with substantial movement (a factor of 0.3 is added for significant levels of strenuous leisure activity); and 2.0 to 2.4 equates to strenuous work or highly active leisure. The respective PAL categories for these estimated levels of activity are *inactive* (1.2–1.5), *low active* (1.6–1.7), *active to very active* (1.8–1.9), and *very active* (2.0–2.4).

A limitation of this data set is that job functions have changed over the past 30 to 40 years and therefore, the rankings may not be as relevant to current occupations. Nonetheless, the data indicate that an occupation must involve substantial movement or strenuous recreational activity must be added to seated work to move an individual into the active or very active category.

The examples in Table 7-1 apply primarily to adults. Normative data for step counts are available for both Canadian and U.S. children (Craig et al., 2010; Tudor-Locke et al., 2009) and indicate that daily steps are higher in boys than in girls and decline with age between 6 and 18 years. The U.S. data would allow calculation of quartiles of step counts by age and sex, and if it were established that step counts in children were strongly associated with PAL as assessed by DLW, this could provide a method of identifying a PAL category. However, as is seen in adults, step counts were only weakly associated with PAL in children, particularly in girls, as shown in a study of Korean schoolchildren (Park et al., 2016). Accordingly, step data may not be optimal for assigning a PAL category.

In the IOM (2002/2005) report on energy, estimates were made of the amount of time a child would need to spend walking at 2.5 mph to move from the inactive PAL category to the low active, active, or very active categories. While not intended to suggest that children would walk for these amounts of time (very active children would likely be doing other activities of higher intensity for shorter periods of time), it indicated the volume of activity associated with various PAL categories. That approach was applied to the updated EERs for reference U.S. boys and girls aged 3 to 18 years (Tables 7-2 and 7-3).

Overall, although uncertainty is common when choosing a PAL category and by extension, when identifying the most appropriate EER equation for either a child or an adult, the planning process for energy intakes includes monitoring body weight and adjusting intake as needed.

Planning Energy Intakes of Individuals

Although EER equations are developed to meet the energy requirements for weight maintenance, the inherent individuality of energy requirements means that an energy intake equal to the calculated EER for an individual could result in weight maintenance (if the person's energy requirement was close to the calculated EER), weight gain (if the person's energy requirement was below the calculated EER), or weight loss (if the person's energy requirement was above the calculated EER). Additional considerations are involved when planning energy intakes for the life stages of pregnancy and lactation and for other individuals whose energy requirements are not specifically addressed by the EER equations (including those seeking to lose or gain weight, as well as individuals with extremely high levels of physical activity). Additional considerations

TABLE 7-2 Minutes of Walking at 2.5 mph (4 km/h) to Move Between Physical Activity Level (PAL) Categories, Boys 3–18 Years

		Difference in EER between activity categories (kcal/d)[b]			Energy cost to walk at 2.5 mph (kcal/kg/min)[c]	Walking time at 2.5 mph to move between PAL categories (min/d)[d]		
Age (y)	Weight (kg)[a]	Low active to inactive	Active to inactive	Very active to inactive		Inactive to low active	Inactive to active	Inactive to very active
3	15.5	142	138	167	0.092	100	97	117
4	17.8	130	152	205	0.089	82	96	129
5	20.5	119	170	249	0.087	67	95	140
6	22.5	109	182	282	0.084	58	96	149
7	26.2	100	207	340	0.082	47	96	158
8	29.5	98	228	386	0.079	42	98	166
9	31.8	95	244	421	0.077	39	100	172
10	38.7	123	293	501	0.074	43	102	175
11	44.6	133	333	578	0.072	41	104	180
12	46.4	122	345	609	0.069	38	108	190
13	55.4	144	407	723	0.067	39	110	195
14	59.9	148	438	784	0.064	39	114	205
15	66.1	180	482	852	0.062	44	118	208
16	66.8	186	488	860	0.059	47	124	218
17	72.1	213	525	918	0.057	52	128	223
18	71	202	517	908	0.054	53	135	237

NOTES: d = day; EER = estimated energy requirement; h = hour; kcal = kilocalorie; kg = kilogram; km = kilometer; min = minute; mph = miles per hour; y = year. See Chapter 5, Table 5-15 for EER equations.

[a] Reference weights from the National Health and Nutrition Examination Survey; (see Table 7-7).

[b] EERs for boys of reference height and weight for each PAL category are shown in Table 7-7. Differences are calculated by subtracting the EER for the inactive category from the EER for each of the other activity categories.

[c] Walking costs determined from treadmill testing (Puyau et al., 2002; Treuth et al., 1998, 2000, 2003).

[d] Calculated as: (Difference in EER between activity categories [kcal/d])/{(Energy cost to walk @ 2.5 mph [kcal/kg/min]) × (body wt [kg])}. For example, for an 18-year-old to move from inactive to low active, 53 minutes/day = 202 kcal/(0.054 kcal/kg/min × 71 kg).

SOURCE: Modified from Table 12-6 (IOM, 2002/2005).

TABLE 7-3 Minutes of Walking at 2.5 mph (4 km/h) to Move Between Physical Activity Level (PAL) Categories, Girls 3–18 Years

		Difference in EER between activity categories (kcal/d[b]			Energy cost to walk at 2.5 mph (kcal/kg/min)[c]	Walking time at 2.5 mph to move between PAL categories (min/d)[d]		
Age (y)	Weight (kg)[a]	Low active to inactive	Active to inactive	Very active to inactive		Inactive to low active	Inactive to active	Inactive to very active
3	14.9	33	95	142	0.095	23	67	100
4	17.7	59	123	208	0.091	37	76	129
5	19.7	87	151	276	0.088	50	87	159
6	22.4	112	178	340	0.085	59	93	179
7	25.7	124	197	374	0.081	60	95	180
8	28.3	144	220	426	0.078	65	100	193
9	33.4	161	249	477	0.074	65	101	193
10	39.5	172	276	516	0.071	61	98	184
11	43.6	200	310	589	0.068	67	105	199
12	52.1	194	331	598	0.064	58	99	179
13	52.2	209	343	631	0.061	66	108	198
14	59.5	207	364	645	0.058	60	105	187
15	58.1	206	359	638	0.054	66	114	203
16	61.8	204	368	643	0.051	65	117	204
17	65.1	199	375	641	0.047	65	123	209
18	62.7	204	371	646	0.044	74	134	234

NOTES: d = day; EER = estimated energy requirement; h = hour; kcal = kilocalorie; kg = kilogram; km = kilometer; min = minute; mph = miles per hour; y = year. See Chapter 5, Table 5-15 for EER equations.

[a] Reference weights from NHANES (see Table 7-8).

[b] EERs for girls of reference height and weight for each PAL category for are shown in Table 7-8. Differences are calculated by subtracting the EER for the inactive category from the EER for each of the other activity categories.

[c] Walking costs determined from treadmill testing (Puyau et al., 2002; Treuth et al., 1998, 2000, 2003).

[d] Calculated as: (Difference in EER between activity categories [kcal/d])/{(Energy cost to walk @ 2.5 mph [kcal/kg/min]) × (body wt [kg])}. For example, for an 18-year-old to move from inactive to low active, 74 minutes/day = 204 kcal/(0.044 kcal/kg/min × 62.7 kg).

SOURCE: Modified from Table 12-7 (IOM, 2002/2005).

of clinical situations (e.g., individuals with clinical conditions or using medications that may affect energy expenditure, or patients who are critically ill or postsurgery) are discussed in Chapter 8.

The following steps show the process for determining an EER for exemplar age/sex and life-stage groups.

Step 1. Select the EER equation and calculate the EER. The EER equations are summarized in Chapter 5 and organized by age/sex group and PAL category (see Table 5-15 for children and adolescents and Table 5-16 for adults). The EER for an individual is calculated by inserting the person's age, height, and weight into the appropriate EER equation.

Nonpregnant, Nonlactating Women

For example, the EER for a 22-year-old woman who is 165 cm in height, weighs 63 kg, and is determined to have a low active PAL based on the guidance provided above is calculated as follows:

$$\begin{aligned} \text{EER} &= 575.77 - (7.01 \times \text{age in years}) + (6.60 \times \text{height in cm}) + (12.14 \times \text{weight in kg}) \\ &= 575.77 - (7.01 \times 22) + (6.60 \times 165) + (12.14 \times 63) \\ &= 575.77 - 154.22 + 1{,}089.0 + 764.82 \\ &= 2{,}275 \text{ kcal/day} \end{aligned}$$

This calculated EER represents the average requirement of women with these values for age, height, weight, and PAL category. Like other nutrients, however, requirements for energy vary—even among individuals with the same age, height, weight, and PAL category. The extent of variability is indicated by the standard error of the predicted value (SEPV), provided for each EER equation in Table 5-8. The SEPV reflects how much an individual's requirement may vary from the value predicted by the EER equation. Assuming that this variation is normally distributed (and based on characteristics of the normal distribution), this means that ~68 percent of individuals with given characteristics will have an energy requirement within 1 standard error of the value predicted by the EER equation, and almost everyone with those characteristics (~95 percent) would have energy requirements within 1.96 SEPV of the value predicted by the equation.

For women aged 19 years or more, the SEPV is 241 kcal/d. For the woman with an EER of 2,275 kcal/d in the above example, this means that ~68 percent of women with her characteristics would have an actual energy requirement between 2,034 and 2,516 kcal/d (the EER of 2,275 +/– 241 kcal), and that 95 percent of women with those characteristics would have actual energy requirements between 1,803 and 2,747 kcal/d (the EER +/– [1.96 × 241]). Thus, it is possible that the woman in the example would have an actual energy requirement reasonably close to the EER. It is also possible that her individual requirement could be considerably less than or more than the EER. For individuals whose energy requirements differ from the EER, providing energy intakes equal to the EER would lead to weight gain or loss over time.

Adolescent Male

The second example is a 15-year-old boy who is 170 cm in height, weighs 66 kg, and is determined to have an "active" PAL. His EER is calculated as follows:

EER = –388.19 + (3.68 × age in years) + (12.66 × height in cm) + (20.46 × weight in kg) + 20 [energy cost of growth]
= –388.19 + (3.68 × 15) + (12.66 × 170) + (20.46 × 66) + 20
= –388.19 + 55.2 +2152.2 + 1350.36 + 20
= 3,190 kcal/day
SEPV = 258 (95% prediction interval: 2,684 – 3,696 kcal/day)

Young Child

The third example is for a young child for whom PAL is not included in the equation. The EER for a 2-year-old boy who is 98 cm in height and weighs 15.5 kg, is calculated as follows:

EER = –716.45 – (1.00 × age in years) + (17.82 × height in cm) + (15.06 × weight in kg) + 20 [energy cost of growth]
= –716.45 – (1.00 × 2) + (17.82 × 98) + (15.06 × 15.5) + 20
= –716.45 – 2 + 1746.4 + 233.4 + 20
= 1,281 kcal/day
SEPV = 104 (95% prediction interval: 1,077 – 1,485 kcal/day)

Older Adult Female

The fourth example is for 70-year-old woman who is 157 cm in height, weighs 70 kg, and is determined to have an "inactive" PAL. Her EER is calculated as follows:

EER = 584.90 – (7.01 × age in years) + (5.72 × height in cm) + (11.71 × weight in kg)
= 584.9 – (7.01× 70) + (5.72 × 157) + (11.71 × 70)
= 584.9 – 490.7 + 898.0 + 819.7
= 1,812 kcal/day
SEPV = 241 (95% prediction interval: 1,340 – 2,284 kcal/day)

Step 2. Monitor body weight over time and adjust intake as required. Because an individual's actual energy requirement may vary considerably from the EER, it is important to monitor body weight over time. If undesired weight gain or loss occurs, energy intake should be adjusted incrementally to maintain the desired weight. In the case of some individual dietary planning applications, using the EER equation to estimate an individual's energy requirement may not be necessary. If the individual is maintaining body weight (or normal rate of growth) and desired level of physical activity, it can be assumed the usual energy intake meets requirements, and planning for other elements of the diet could proceed without identifying a specific energy intake.

Pregnant and Lactating Women

Planning energy intakes during pregnancy and lactation follows the same general procedures as described above, with additional considerations for these life stages reflected in the EER equations.

Step 1 for Pregnancy. Select the appropriate EER equation and calculate the EER. During the second and third trimesters of pregnancy, calculating the EER for pregnancy requires an individual's current height, weight, age, PAL category, prepregnant body mass index (BMI), and the number of gestational weeks. During the first trimester (conception to 13 completed weeks) a woman's EER is the same as her nonpregnant EER for a given PAL category; accordingly, the pregnancy equations are not used. This is because the embryo and placenta are forming through cell division and differentiation, which does not require extra calories (IOM and NRC, 2009).

During the second and third trimesters, the EER equation includes an increment for the deposition of new tissue necessary to support the products of conception (e.g., fetus, placenta, breast and uterus tissue growth, plasma volume expansion) (see Table 5-17). The increment varies depending on a woman's prepregnant BMI (underweight, +300 kcal/d; normal weight, +200 kcal/d; overweight, +150 kcal/d; obese, –50 kcal/d). It is also possible that a woman's PAL category may change as the pregnancy progresses. Thus, selecting the appropriate EER equation for pregnancy is based on current physical activity level, weight, age, height, and weeks of pregnancy, plus the appropriate extra calories per BMI category needed for energy deposition.

The IOM gestational weight gain recommendations apply to all women, regardless of age (IOM and NRC, 2009). In the case of women who become pregnant during adolescence, the age-appropriate and PAL-appropriate EER equation should be used for the first trimester and the pregnancy equations for the second and third trimesters, according to the individual's physical activity level. Additional calories for energy deposition are added according to the woman's prepregnancy BMI (i.e., underweight, +300 kcal/d; normal weight, +200 kcal/d; overweight, +150 kcal/d; obese, –50 kcal/d). Two examples of how the EER would change during pregnancy are shown in Box 7-1; one for a woman with a prepregnant BMI in the normal range and one for a woman with a prepregnant BMI in the obese range. These examples also illustrate the differences between the new EER compared to the 2005 EER.

Step 2 for Pregnancy. Monitor body weight and rate of weight gain for the pregnant woman and adjust energy intake as required. During pregnancy, it is crucial that weight gain is monitored, and energy intake is adjusted as required to achieve the appropriate rate and amount of weight gain throughout pregnancy to avoid adverse outcomes for the mother and/or child (Goldstein et al., 2017).

BOX 7-1
Examples of Changes in EER During Pregnancy

The following examples show changes in EER during the course of pregnancy for 28-year-old women 170 cm in height with active PAL and either a normal or obese prepregnancy BMI.

	Weight* kg (lb)	EER**	IOM (2002/2005) EER
Person A (BMI = normal)			
First trimester	65 (143)	2,428	2,544
20 weeks	69 (152)	2,914	2,884
32 weeks	75 (165)	3,072	2,980
Person B (BMI = obese)			
First trimester	92 (202)	2,761	2,865
20 weeks	94.5 (208)	2,871	3,205
32 weeks	97 (213)	3,002	3,301

*First trimester uses the prepregnancy weight; second and third trimesters use current weight and assume that weight gain is occurring at recommended rates.

**EER first trimester calculated using EER equation for nonpregnant active women aged 19+ years: EER (kcal/d) = 710.25 – (7.01 × age in y) + (6.54 × height in cm) + (12.34 × weight in kg). EERs for pregnancy calculated using the pregnancy equation for active women: EER (kcal/d) = –223.84 – (2.04 × age in y) + (13.23 × height in cm) + (8.15 × weight in kg) + (9.16 × gestation in wk) + increment for tissue deposition (based on prepregnant BMI category: +300 [underweight], +200 [normal weight], +150 [overweight], –50 [obese]).

Step 1 for Lactation. Select the appropriate EER equation and calculate the EER. To plan for energy intake during lactation, the EER equation for the appropriate PAL category for women aged 19 years and older is used (or for adolescents, the EER equation for girls), to which an increment is added (see Tables 5-18 and 5-19). The increments are based on the energy cost of producing milk and energy mobilized among women who are exclusively breastfeeding during the first 6 months of lactation (a net of 404 kcal/d for months 0 to 6 postpartum) and then partially breastfeeding beyond 6 months (380 kcal/d for months 7 to 12 postpartum), as described in Chapter 5. This additional energy cost assumes a gradual weight loss of 0.64 kg/month in the first 6 months postpartum. Box 7-2 shows examples of changes in EER for two women of different BMI status during the postpartum period.

Step 2 for Lactation: Monitor body weight and adjust energy intake as required. Because an individual's actual energy requirement may vary considerably from the EER, it is important to monitor the rate of weight loss for the postpartum woman and adjust energy intake as required or desired to allow for quicker return to prepregnancy weight. As women resume work and leisure physical activity, energy expenditure may increase but this can be offset by decreased energy needs attributable to partial breastfeeding and the introduction of complementary foods to the infant over the course of the postpartum period. Evidence exists to support greater weight loss during the postpartum period without compromising the volume or quality of breast milk if no additional calories are consumed beyond the nonpregnant EER (Lovelady, 2011).

Individuals Seeking to Lose or Gain Weight

The EER equations reflect estimated requirements for weight *maintenance* (and normal growth, if applicable), irrespective of body weight status and do not predict energy requirements for those seeking to lose or gain weight. However, the equations can be used to identify energy intakes that would likely lead to weight gain or loss. By adding or subtracting 1.96 × SEPV (see Table 5-8) to (or from) the EER, energy intakes can be identified that would exceed or would be inadequate to maintain weight in almost all individuals with specified characteristics.

For example, consider a 45-year-old man with a low active PAL who is 1.75 m in height, weighs 100 kg, and wants to lose weight. His EER would be calculated as 3,041 kcal. The SEPV for men aged 19 years or older is 342 kcal. Thus, an energy intake of 3,041 – (1.96 × 342), or 2,371 kcal, would be predicted to lead to weight loss in almost all men with his characteristics. Conversely, for a man of the same age, height, and PAL category, but

BOX 7-2
Examples of Changes in EER During Lactation

The following examples show changes in EER for 28-year-old women 170 cm in height with active PAL and a BMI of either normal or obese at the time of the postpartum weight measurement.

	Weight at first post-partum visit kg (lb)	Lactation EER* first month postpartum	Lactation EER* 3 months postpartum	Lactation EER* 5 months postpartum	Lactation EER** 7 months postpartum
Person A (BMI = normal)	65 (143)	2,828	2,804	2,788	2,760
Person B (BMI = obese)	92 (202)	3,161	3,138	3,122	3,094

* 0–6 months active: EER (kcal/d) = 710.25 – (7.01 × age in y) + (6.54 × height in cm) + (12.34 × weight in kg) + 540 (kcal/d) – 140 (kcal/d). At 3 months, total weight loss is assumed to be 1.9 kg. At 5 months, total weight loss is assumed to be 3.2 kg.

**7–9 months active: EER (kcal/d) = 710.25 – (7.01 × age in y) + (6.54 × height in cm) + (12.34 × weight in kg) + 380 (kcal/d). At 7 months, total weight loss is assumed to be 3.84 kg.

who weighs 55 kg, EER would be calculated as 2,368 kcal. If he wanted to gain weight, an energy intake of 2,368 + (1.96 × 342), or 3,038 kcal, would be predicted to lead to weight gain in almost all men with his characteristics. These values might be used to identify starting points for weight change and would subsequently be modified as required to maintain an appropriate rate of weight loss or gain. While negative energy balance is a prerequisite for weight loss and positive energy balance is a prerequisite for weight gain, body weight management is a multifaceted process that includes many other aspects in addition to modifying energy intake (e.g., Wharton et al., 2020).

Individuals with Extremely High Physical Activity Levels

By definition, the EER equations do not predict energy requirements of those with a PAL greater than 2.5, and individuals undergoing strenuous physical activity for prolonged periods of time (e.g., elite athletes undergoing heavy training) often have PAL values in excess of this threshold (e.g., Westerterp, 2018). Accordingly, they would not meet their energy requirements if they consumed an energy intake equal to their calculated EER, even using the equations for those with a very active PAL.

Planning Energy Intakes of Groups

Planning energy intake levels for groups is challenging, as group members may vary considerably in terms of age, sex, body size, and physical activity level, and planners may or may not have access to the individual characteristics of group members. As with planning energy intakes for individuals, the process includes selecting the appropriate EER equation (or equations) to calculate EER, followed by monitoring body weight over time and adjusting the energy content of the food provided as required.

All Age/Sex Groups

Step 1. Select the EER equation, and calculate the EER. The EER equations can be used in the initial stage of planning for the energy intakes of groups, although the approach differs depending on whether the planner has access to complete data on the individual characteristics of all group members (i.e., sex, age, height, weight, and PAL category) and whether the members of the group are homogeneous in terms of sex, age grouping, and PAL category (i.e., whether all group members would use the same EER equation). An overview of how this could be accomplished in each situation is described in Table 7-4.

Tables 7-5 through 7-14 show EERs for Americans and Canadians of median height and weight, for their sex/age group. The first series of tables (Tables 7-5 to 7-10) present values for Americans by age group and by sex, and the second series (Tables 7-11 to 7-14) presents values for Canadians. Because many groups include members from all weight status categories (i.e., underweight, normal weight, overweight, and obese), these tables show EERs based on median heights and weights of the overall population. However, additional tables showing EERs calculated separately by weight category (i.e., based on median heights and weights of individuals who are underweight, normal weight, overweight, and obese) are provided in Appendix M for Americans and Canadians. These may be useful if the planner knows that most or all group members fall into a specific weight status category.

Data on reference heights and weights for Canadian children aged less than 3 years were not available. Based on similar heights and weights of U.S. and Canadian children at 3 years of age, however, it appears reasonable to apply the U.S. reference values to Canadian infants and toddlers aged less than 3 years.

The committee identified a number of limitations in the approach to planning energy intakes of groups (Table 7-4) with respect to the variability of energy requirements among group members. As for individuals, the EER will closely approximate the actual requirements of some group

TABLE 7-4 Application of the EER Equation to Plan Energy Intakes of Groups

Complete data on age, sex, height, weight, and PAL category available to planner	Groups are similar in age grouping, sex, and PAL category	
	Yes	No
Yes	Example: Low active male prison inmates aged 19 years or older Use mean or median values for height, weight, and age of group members to calculate the mean or median EER for the group	Example: Inactive older male and female adults living in a residential care facility (sex differs). Use mean or median values for height, weight, and age of men and women to calculate mean or median EERs for each sex separately Determine a weighted EER by using the proportions of men and women. For example, if 30% men and 70% women, weighted EER = (0.3 × male EER) + (0.7 × female EER)
No	Example: Women aged ~30–50 (no data on individual age, height, and weight) participating in a 1-week yoga camp. Women will likely be "active" at the camp. Use EER for reference individual in this age/sex PAL group (see Table 7-10 or 7-14, which shows EERs for reference U.S. and Canadian women)	Example: School lunch program for primary school boys and girls age 6–12 years Determine median age of group (e.g., 9 years) Choose a PAL category using any available information Use EERs for reference individuals of median age in selected PAL category (see Tables 7-7 and 7-8 for U.S. or Tables 7-11 and 7-12 for Canadian boys and girls) to calculate EERs for age/sex groups Determine a weighted EER using the proportions of boys and girls in the group

NOTE: EER = estimated energy requirement; PAL = physical activity level.

members but will overestimate or underestimate the actual requirements of others. The implications will vary depending on whether individual group members can choose the amounts of food they receive (e.g., they can have larger or smaller portions of food items as desired), or whether there is no choice and everyone in the group receives an identical amount

TABLE 7-5 Estimated Energy Requirements (EER), U.S. Boys Aged 0–35 Months, Based on Median Length/Height and Weight by Age

	Median Length/Height and Weight[a]				
Age Group (mo)[b]	Length/ Height (cm)	Length/ Height (in)	Weight (kg)	Weight (lb)	EER[c] (kcal/d)
Birth–2	56.5	22.2	5.0	11.0	566
3–5	64.4	25.4	7.2	15.8	589
6–8	69.5	27.4	8.9	19.5	675
9–11	73.0	28.7	9.4	20.8	745
12–14	76.4	30.1	10.4	22.9	821
15–17	79.2	31.2	11.1	24.4	881
18–20	82.6	32.5	11.8	26.1	952
21–23	86.4	34.0	12.3	27.1	1,027
24–26	87.9	34.6	12.6	27.7	1,058
27–29	91.4	36.0	13.7	30.2	1,136
30–32	93.3	36.7	14.6	32.1	1,183
33–35	94.9	37.4	14.7	32.5	1,213

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; mo = month.

[a] For U.S. population, based on NHANES 2015–2018, estimated for age group.

[b] Age used to predict EER is based on specific age: birth–2 mo: 1 mo; 3–5 mo: 4 mo; 6–8 mo: 7 mo; 9–11 mo: 10 mo; 12–14 mo: 13 mo; 15–17 mo: 16 mo; 18–20 mo: 19 mo; 21–23 mo: 22 mo; 24–26 mo: 25 mo; 27–29 mo: 28 mo; 30–32 mo: 31 mo; 33–35 mo: 34 mo.

[c] Uses EER equations for boys, 0–2 years.

TABLE 7-6 Estimated Energy Requirements (EER), U.S. Girls Aged 0–35 Months, Based on Median Length/Height and Weight by Age

	Median Length/Height and Weight[a]				
Age Group (mo)[b]	Length/Height (cm)	Length/Height (in)	Weight (kg)	Weight (lb)	EER[c] (kcal/d)
Birth–2	55.9	22.0	4.9	10.9	531
3–5	62.6	24.7	6.7	14.8	546
6–8	67.5	26.6	7.9	17.4	604
9–11	71.5	28.2	8.9	19.6	689
12–14	75.8	29.9	10.1	22.2	780
15–17	77.9	30.7	10.3	22.7	817
18–20	82.2	32.4	10.9	24.1	881
21–23	84.9	33.4	11.8	25.9	956
24–26	87.7	34.5	12.3	27.0	1,011
27–29	89.2	35.1	12.6	27.8	1,051
30–32	92.0	36.2	13.4	29.6	1,122
33–35	94.4	37.2	14.2	31.3	1,192

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; mo = month.

[a] For U.S. population, based on NHANES 2015–2018, estimated for age group.

[b] Age used to predict EER is based on specific age: birth–2 mo: 1 mo; 3–5 mo: 4 mo; 6–8 mo: 7 mo; 9–11 mo: 10 mo; 12–14 mo: 13 mo; 15–17 mo: 16 mo; 18–20 mo: 19 mo; 21–23 mo: 22 mo; 24–26 mo: 25 mo; 27–29 mo: 28 mo; 30–32 mo: 31 mo; 33–35 mo: 34 mo.

[c] Uses EER equations for girls, 0–2 years.

TABLE 7-7 Estimated Energy Requirements (EER) for Overall Population, U.S. Boys Aged 3–18 years, Based on Median Height and Weight for Age and Physical Activity Level (PAL) Category

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age (y)[c]	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL	Low active PAL	Active PAL	Very active PAL
3	99.2	39.1	15.5	34.1	1,078	1,220	1,216	1,245
4	105.4	41.5	17.8	39.2	1,188	1,318	1,340	1,393
5	112.4	44.3	20.5	45.1	1,318	1,437	1,488	1,567
6	118.0	46.5	22.5	49.5	1,421	1,530	1,603	1,703
7	126.1	49.6	26.2	57.6	1,578	1,678	1,785	1,918
8	131.8	51.9	29.5	64.9	1,700	1,798	1,928	2,086
9	136.4	53.7	31.8	70.0	1,803	1,898	2,047	2,224
10	141.1	55.6	38.7	85.1	1,959	2,082	2,252	2,460
11	148.3	58.4	44.6	98.1	2,134	2,267	2,467	2,712
12	153.9	60.6	46.4	102.1	2,234	2,356	2,579	2,843
13	163.6	64.4	55.4	121.9	2,482	2,626	2,889	3,205
14	170.0	66.9	59.9	131.8	2,623	2,771	3,061	3,407
15	172.7	68.0	66.1	145.4	2,744	2,924	3,226	3,596
16	172.6	68.0	66.8	147.0	2,755	2,941	3,243	3,615
17	174.9	68.9	72.1	158.6	2,859	3,072	3,384	3,777
18	175.5	69.1	71.0	156.2	2,856	3,058	3,373	3,764

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated for each age by year.

[b] Uses EER equations for boys, 3–18 years

[c] For ages 3–8 years: inactive: $1.0 \leq PAL < 1.31$; low active: $1.31 \leq PAL < 1.44$; active: $1.44 \leq PAL < 1.59$; very active: $1.59 \leq PAL < 2.5$. For ages 9–13 years: inactive: $1.0 \leq PAL < 1.44$; low active: $1.44 \leq PAL < 1.60$; active: $1.60 \leq PAL < 1.77$; very active: $1.77 \leq PAL < 2.5$. For ages 14–18 years: inactive: $1.0 \leq PAL < 1.57$; low active: $1.57 \leq PAL < 1.74$; active: $1.74 \leq PAL < 1.94$; very active: $1.94 \leq PAL < 2.5$.

TABLE 7-8 Estimated Energy Requirements (EER) for Overall Population, U.S. Girls Aged 3–18 years, Based on Median Height and Weight for Age and Physical Activity Level (PAL) Category

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age (y)[c]	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL	Low Active PAL	Active PAL	Very Active PAL
3	96.9	38.1	14.9	32.8	1,075	1,108	1,170	1,217
4	104.6	41.2	17.7	38.9	1,166	1,225	1,289	1,374
5	112.1	44.1	19.7	43.3	1,241	1,328	1,392	1,517
6	119.3	47.0	22.4	49.3	1,325	1,437	1,503	1,665
7	123.7	48.7	25.7	56.5	1,396	1,520	1,593	1,770
8	129.8	51.1	28.3	62.3	1,470	1,614	1,690	1,896
9	136.5	53.7	33.4	73.5	1,606	1,767	1,855	2,083
10	142.3	56.0	39.5	86.9	1,737	1,909	2,013	2,253
11	150.8	59.4	43.6	95.9	1,856	2,056	2,166	2,445
12	154.3	60.7	52.1	114.6	2,009	2,203	2,340	2,607
13	157.7	62.1	52.2	114.8	2,017	2,226	2,360	2,648
14	161.2	63.5	59.5	130.9	2,139	2,346	2,503	2,784
15	160.0	63.0	58.1	127.8	2,082	2,288	2,441	2,720
16	161.7	63.7	61.8	136.0	2,138	2,342	2,506	2,781
17	162.4	63.9	65.1	143.2	2,178	2,377	2,553	2,819
18	162.3	63.9	62.7	137.9	2,114	2,318	2,485	2,760

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated for each age by year.

[b] Uses EER equations for girls, 3–18 years.

[c] For ages 3–8 years: Inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 years: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 years: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

TABLE 7-9 Estimated Energy Requirements (EER) for Overall Population, Adult U.S. Men, Based on Median Height and Weight for Age Group

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[d]	Low active PAL	Active PAL	Very active PAL
Overall								
19–30	176.1	69.3	81.4	179.1	2,775	2,988	3,177	3,516
31–50	176.3	69.4	89.9	197.8	2,733	2,955	3,151	3,519
51–70	174.9	68.9	88.7	195.1	2,491	2,709	2,907	3,258
> 70	172.2	67.8	83.3	183.3	2,181	2,389	2,586	2,896
19+	175.4	69.1	87.2	191.8	2,581	2,799	2,994	3,345

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated for age group.

[b] Uses EER equations for adult men.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y or older: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

TABLE 7-10 Estimated Energy Requirements (EER) for Overall Population, Adult U.S. Women, Based on Median Height and Weight for Age Group

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[d]	Low active PAL	Active PAL	Very active PAL
Overall								
19–30	162.7	64.1	69.3	152.5	2,152	2,316	2,454	2,683
31–50	162.5	64.0	75.0	165.0	2,112	2,278	2,418	2,647
51–70	160.8	63.3	74.8	164.6	1,960	2,125	2,264	2,489
> 70	156.8	61.7	69.7	153.3	1,737	1,896	2,035	2,249
19+	161.2	63.5	73.2	161.0	2,014	2,178	2,317	2,543

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015-–2018, estimated for age group.

[b] Uses EER equations for adult women.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y or older: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

TABLE 7-11 Estimated Energy Requirements (EER), Canadian Boys Aged 3–18, Based on Median Height and Weight for Age Group and Physical Activity Level (PAL) Category

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age (y)[c]	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[c]	Low active PAL	Active PAL	Very active PAL
3	100.1	39.4	16.0	35.2	1,096	1,238	1,237	1,271
4	106.6	42.0	17.7	38.9	1,202	1,327	1,353	1,409
5	112.9	44.4	19.9	43.8	1,316	1,429	1,482	1,561
6	120.4	47.4	22.2	48.8	1,448	1,544	1,627	1,733
7	126.7	49.9	24.9	54.8	1,569	1,657	1,766	1,897
8	132.1	52.0	28.4	62.5	1,689	1,778	1,910	2,065
9	138.9	54.7	32.5	71.5	1,845	1,934	2,093	2,278
10	142.8	56.2	35.8	78.8	1,943	2,038	2,214	2,419
11	147.3	58.0	39.4	86.7	2,052	2,153	2,348	2,575
12	159.4	62.8	48.4	106.5	2,332	2,444	2,689	2,974
13	164.7	64.8	55.0	121.0	2,491	2,627	2,895	3,213
14	168.7	66.4	63.6	139.9	2,655	2,835	3,120	3,473
15	173.0	68.1	68.3	150.3	2,777	2,971	3,275	3,652
16	175.6	69.1	69.7	153.3	2,832	3,025	3,340	3,728
17	178.3	70.2	71.0	156.2	2,888	3,079	3,404	3,804
18	175.8	69.2	72.0	158.4	2,873	3,081	3,397	3,792

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated for each age (y).

[b] Uses EER equations for boys, 3–18 years.

[c] For ages 3–8 y: inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 y: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 y: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

TABLE 7-12 Estimated Energy Requirements (EER), Canadian Girls Aged 3–18, Based on Median Height and Weight for Age Group and Physical Activity Level (PAL) Category

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age (y)[c]	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[c]	Low active PAL	Active PAL	Very active PAL
3	99.5	39.2	15.6	34.3	1,109	1,151	1,213	1,274
4	105.6	41.6	17.6	38.7	1,172	1,236	1,299	1,391
5	112.3	44.2	19.8	43.6	1,244	1,332	1,396	1,522
6	121.1	47.7	22.9	50.4	1,349	1,468	1,534	1,705
7	124.4	49.0	24.2	53.2	1,377	1,507	1,574	1,761
8	132.1	52.0	27.9	61.4	1,482	1,637	1,710	1,932
9	136.0	53.5	29.5	64.9	1,535	1,703	1,778	2,018
10	145.2	57.2	37.6	82.7	1,729	1,918	2,012	2,279
11	149.5	58.9	40.1	88.2	1,786	1,987	2,086	2,371
12	157.8	62.1	49.4	108.7	1,992	2,208	2,332	2,632
13	161.0	63.4	52.6	115.7	2,051	2,274	2,406	2,714
14	162.2	63.9	53.3	117.3	2,041	2,267	2,401	2,714
15	163.5	64.4	56.5	124.3	2,085	2,309	2,452	2,761
16	164.8	64.9	58.7	129.1	2,111	2,336	2,486	2,794
17	163.4	64.3	61.6	135.5	2,126	2,338	2,500	2,787
18	165.1	65.0	59.9	131.8	2,089	2,313	2,467	2,772

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated for each age (y).

[b] Uses EER equations for girls, 3–18 years.

[c] For ages 3–8 y: inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 y: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 y: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

TABLE 7-13 Estimated Energy Requirements (EER) for Overall Population, Adult Canadian Men, Based on Median Height and Weight for Age Group

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age group[c] (y)	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[d]	Low active PAL	Active PAL	Very active PAL
Overall								
19–30	178.4	70.2	79.7	175.3	2,766	2,982	3,165	3,519
31–50	176.4	69.4	84.0	184.8	2,651	2,867	3,058	3,408
51–70	174.5	68.7	84.8	186.6	2,433	2,647	2,842	3,177
> 70	171.5	67.5	81.9	180.2	2,156	2,362	2,560	2,858
19+	175.9	69.3	83.2	183.0	2,528	2,743	2,934	3,276

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated for age group.

[b] Uses EER equations for adult men.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y or older: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

TABLE 7-14 Estimated Energy Requirements (EER) for Overall Population, Adult Canadian Women, Based on Median Height and Weight for Age Group

	Median Height and Weight[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in)	Weight (kg)	Weight (lb)	Inactive PAL[d]	Low active PAL	Active PAL	Very active PAL
Overall								
19–30	163.4	64.3	65.0	143.0	2,105	2,268	2,406	2,635
31–50	163.2	64.3	68.2	150.0	2,037	2,200	2,339	2,568
51–70	160.4	63.1	69.0	151.8	1,890	2,051	2,190	2,413
> 70	157.8	62.1	68.3	150.3	1,727	1,886	2,024	2,240
19+	162.1	63.8	68.1	149.8	1,959	2,122	2,260	2,487

NOTE: cm = centimeter; d = day; in = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year

[a] For Canadian population, based on CHMS 2012–2019, estimated for age group.

[b] Uses EER equations for adult women.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y or older: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

of food. They will also vary depending on whether the planner provides all meals and snacks throughout the day, or just a single meal.

If meals are provided in a setting in which individuals can choose the amounts they receive, it is possible that providing a total amount of food energy equal to the mean or median EER multiplied by the number of group members could meet the requirements of almost all members of the group. This is possible because freely selected energy intakes are highly correlated with energy requirements. Those with above-average requirements generally select larger portions to meet their higher energy needs, while those with below-average requirements generally select smaller portions. Thus, in this "free choice" setting, most group members could meet their energy requirements if the average amount of food provided equaled the EER calculated for the group (with appropriate allowances for food wastage). In contrast, if everyone in the group receives an identical amount of food energy and does not have the opportunity to augment it, those with above-average energy requirements will not meet their energy needs.

The consequences of the nature of food delivery (i.e., the opportunity for variable or additional portions versus the provision of identical amounts to all group members) are considerably greater when the planner is providing all meals and snacks consumed throughout the day, such as could occur in a prison setting or a residential care facility. Those with above-average energy needs who do not meet their energy requirements will inevitably lose weight. Those with below-average energy needs, however, will not necessarily gain weight, as they have the option of not consuming all the food provided to them. In contrast, if the planner is providing only a single meal and group members have free access to food at other times during the day, those whose energy needs are not met during the single meal may be able to compensate by consuming more at other times during the day.

Step 2. Monitor body weight over time, and adjust intake as required. As discussed previously, monitoring body weight over time is particularly critical in group feeding situations in which all individuals in the group are provided identical portions in their meals and snacks, and in which all daily meals and snacks are provided with little or no opportunity to obtain food from other sources. This could apply in settings such as prisons and some residential care facilities. If the food provided contains an amount of energy based on the EER calculated for the group, some individuals in the group will not meet their energy needs and will lose weight. Thus, monitoring body weight and establishing mechanisms to provide additional food to those whose energy needs are not being met are essential.

ASSESSING ADEQUACY OF ENERGY INTAKES

The overall purpose of assessing dietary intakes is to determine whether intake is adequate (meets or exceeds the requirement for the specific biological indicator of adequacy used to determine the requirement for a given nutrient) but not excessive (falls below the intake level at which potential risk of adverse effects of excessive nutrient intake begins to increase). For energy, the biological indicator of adequacy used to define the requirement is maintenance of current body weight/composition (or appropriate rates of growth in growing individuals) and current level of physical activity. It is recognized that in some cases, modification of body weight/composition may be appropriate (e.g., weight loss in an individual with obesity and type 2 diabetes), but the EER equations were not developed with the objective of leading to weight gain (or loss) in nongrowing individuals or groups.

Procedures for the assessment of dietary intakes of individuals and groups are detailed elsewhere (IOM, 2000b). Briefly, for individuals, one can determine the degree of confidence that the individual's intake of a nutrient meets his or her requirement for the indicator of adequacy and is not excessive, whereas for groups one can determine the proportion of the group with usual intakes below their requirement for the indicator of adequacy, as well as the proportion with usual intakes associated with potential risk of excess.

These methods for assessing dietary nutrient intakes and determining the likelihood or prevalence of inadequacy or excess cannot be used for energy. Their use is based on a number of assumptions (IOM, 2000b), including that nutrient intakes and requirements are not highly correlated. This is thought to be true for almost all other nutrients. For example, an individual with an above-average requirement for vitamin C does not intuitively consume larger amounts of vitamin C. However, it is not true for energy, as energy intakes and requirements are highly correlated. Furthermore, as described in Chapter 6, misreporting of energy intakes is pervasive in national surveys of dietary intakes and is not random. Underreporting occurs in most age/sex groups, and its extent appears to vary by factors such as age, sex, and body weight status (see Chapter 6). Accordingly, assessing the adequacy of energy intake based on self-reported dietary intake data is not valid.

However, unlike the case for many other food components, the biological indicator of adequacy for energy (body weight maintenance) is easily measured, without the need for laboratory assessments. By definition, nongrowing individuals maintaining a stable weight are meeting their energy requirements, while those currently gaining or losing weight are exceeding or falling below their requirements, respectively. For growing children and pregnant women, meeting the energy requirement is reflected by gaining the expected amount of weight over time. Inadequate or excessive intakes in these groups are reflected by failure to gain the expected amount of weight (or, in some cases, by weight loss) or gaining excessive amounts of weight, respectively.

At the population level, insights about the overall adequacy of energy intake are provided by assessing the proportions of the population classified in various body weight categories (i.e., underweight, normal weight, overweight, and obesity) using BMI in adults or BMI *Z*-scores/percentiles in children. Although individuals within each category may be currently meeting, exceeding, or falling below their requirement to maintain their current weight (e.g., some underweight individuals may be maintaining their weight while others may be gaining or losing weight), the prevalence of underweight, normal weight, and overweight/obesity in a population provide useful information about the overall long-term level of energy adequacy in that population and its subgroups.

The examples below illustrate why it is not appropriate to assess adequacy of energy intake by comparing self-reported dietary intakes obtained from either individuals or groups and why assessment of body weight stability and relative body weight status provides information that has greater validity and utility.

Assessing Energy Intakes of Individuals

Short-term changes in body weight can be interpreted as reflecting energy intakes that are inadequate (if weight is being lost) or excessive (if weight if being gained) to maintain the individual's usual weight. In some cases, this may be desirable (e.g., a reasonable rate of weight loss in an individual with obesity), while in others it may be a reason for concern (e.g., weight loss in an underweight individual). It must also be recognized that, particularly when working with individuals, there are limitations to the use of BMI to determine whether an individual has a normal body weight and composition.

To illustrate, in the example of a 22-year-old, low active woman, her EER is calculated as 2,275 kcal/d based on a height of 165 cm and a weight of 63 kg. She indicates that her weight has been stable for the past 2 years. She kept a 3-day food record, and it revealed that her energy intake averaged 1,820 kcal/d. The difference between her EER and her reported intake is 455 kcal/d (2,275 kcal–1,820 kcal). A discrepancy of that magnitude would lead to an expectation that her energy intake would be inadequate to meet her requirement and that she would be losing weight. However, her weight is stable. In this situation, a large number of factors could have contributed to the discrepancy. These include:

- It is possible that she reported her intake accurately in the 3-day food record, but her intake during those 3 days may have differed from her usual intake. Based on a yearlong study of 29 individuals, estimating the average energy intake of an individual within 10 percent of their true mean value required an average of 31 days of intake records (Basiotis et al., 1987). Clearly, this is not realistic in almost all situations.
- She may have underreported her intake in the 3-day record (perhaps because of difficulty in estimating portion sizes or forgetting to record some food items).
- Although her reported intake is considerably lower than the EER, it is at least theoretically possible that she may have reported her intake accurately and that it reflected her usual intake. In this case, she could be an individual whose requirement is at the lower end of the range for which the EER is the average. For adult women, the range encompasses the EER plus or minus two times the SEPV of 241 kcal, or in this case 1,793–2,757 kcal/d. Her reported intake of 1,820 kcal is 455 kcal below the EER, and is thus at the bottom of the range, but is still within expected normal variability.
- It is possible that the low active PAL category may have been inappropriate. For example, her activity level may be more accurately classified as being in the inactive range, and thus her EER was overestimated by using the EER equation for low active women.
- Any combination of the above factors may have contributed to her reported intake being considerably below the EER, despite her stable weight.

Thus, based on the observation that her current weight is stable, one can conclude that her usual energy intake is meeting her requirement. In addition, her current height and weight translate to a BMI of 23.1, which is within the normal weight range. In conclusion, neither weight loss nor weight gain would be indicated from an overall health perspective.

Assessing Energy Intakes of Groups

As was true for individuals, it is not appropriate to use reported energy intake to determine the prevalence of energy inadequacy or excess in a group. For many nutrients, prevalence of inadequacy in a group is estimated by determining the proportion of the group's usual nutrient intake distribution that falls below the EAR (IOM, 2000b), but this cannot be done for energy because intakes are highly correlated with requirements and underreporting is prevalent.

If energy intakes of all members of a group met their individual energy requirements for weight maintenance, one would expect the mean or median energy intake of the group to closely approximate the mean or median EER for the group. Half the group (those with lower-than-average requirements) would have intakes below the EER and the other half (with higher-than-average requirements) would have intakes above it. Thus, in this "ideal situation" the prevalence of intakes below the EER would be 50 percent but the prevalence of inadequacy (and of excess) would be zero. This is in significant contrast to what is observed with other nutrients, for which intakes are not highly correlated with requirements. For example, if 50 percent of a population group had vitamin C intakes below the EAR for vitamin C, one would expect that a similar proportion would not meet the requirement for the biological indicator of adequacy used to establish the EAR (which was near saturation of neutrophils with vitamin C without excessive urinary excretion) (IOM, 2000a).

Reported energy intakes from national surveys indicate that intakes are generally well below the EER calculated for the group for adults. Figure 7-1 shows the median EERs calculated for U.S. and Canadian women aged 19 years or older with normal weight, overweight, and obesity. For each BMI category, EERs were determined for inactive, low active, active, and very active women at median height and weight for that BMI category and at age 50 (an approximate median age for women aged 19 years or older). In Figure 7-1, the lowest value is the EER for the inactive group and the highest value shown is the EER for the very active group. The figure also shows the median energy intakes for women who have normal weight, overweight, and obesity as reported by NHANES (for U.S. women) or the CCHS (for Canadian women).

Reported intakes are not subdivided by PAL category, as the surveys do not collect data that would permit PAL category to be determined. Nevertheless, in all cases the reported median energy intakes were well below the EER, even for inactive women. Furthermore, the gap between reported intakes and the EER increased across BMI categories. Based on the data shown in Figure 7-1, one would expect that the majority of adult women would be losing weight, as reported median intakes were lower than the EER for the least active women. Systematic underreporting of energy intakes underlies the differences between reported intakes of groups and the EER for the group.

Instead of assessing the adequacy of the energy intake of groups from their reported intakes, data on the body weight status of the group should be used to draw conclusions about the long-term adequacy of

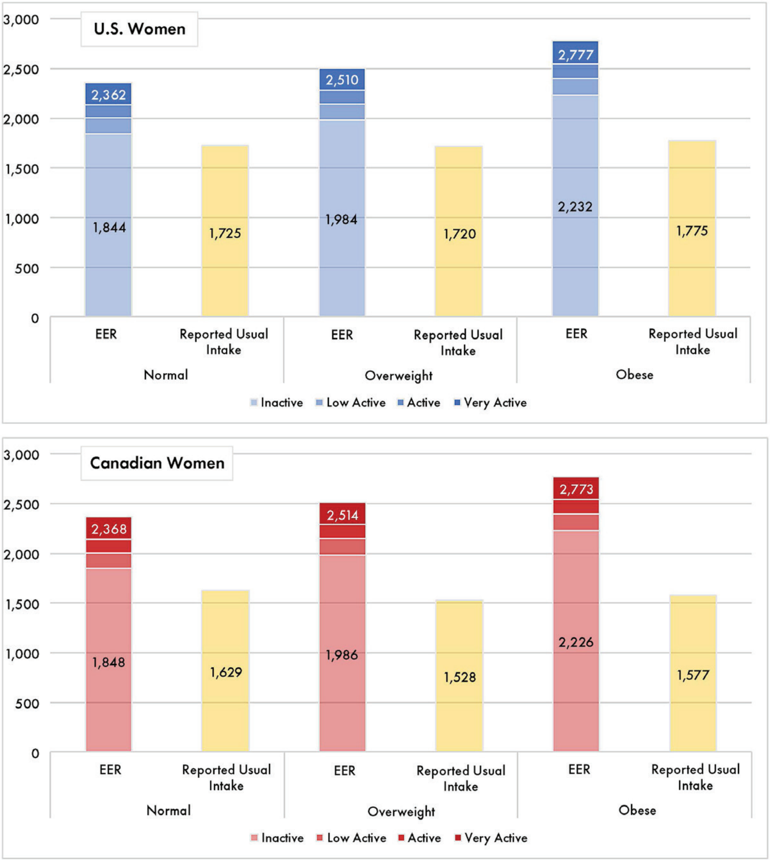

FIGURE 7-1 Median Estimated Energy Requirements (EERs) for U.S. and Canadian women aged 19 years or older with normal weight, overweight, and obesity, compared to median energy intakes reported in NHANES (U.S. women) and CCHS (Canadian women).
NOTE: EERs were calculated for inactive, low active, active, and very active U.S. and Canadian women at age 50 and of median height and weight within each BMI category (normal weight, overweight, obesity).
SOURCE: Median usual energy intakes for women with normal weight, overweight, obesity were determined from NHANES (U.S. women) and the CCHS 2015 Nutrition (Canadian women).

group or population energy intakes. Figure 7-2 shows the distribution of body weight status categories for adult women in the United States and Canada. Low proportions of women have a BMI classified as underweight (which would suggest relative energy inadequacy over the long term),

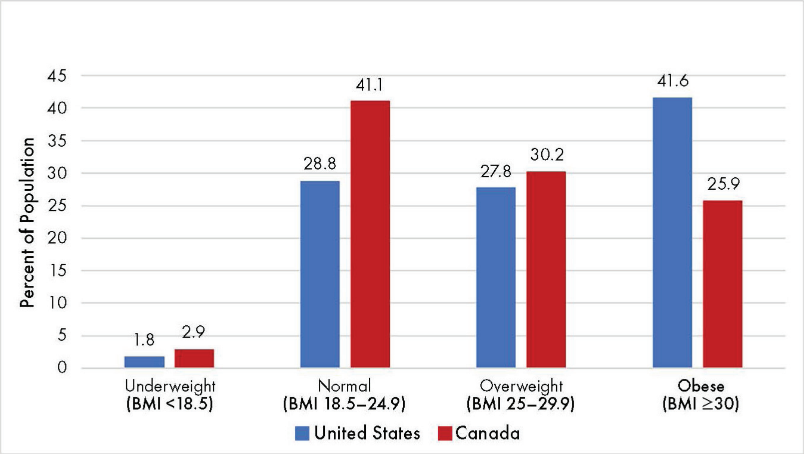

FIGURE 7-2 Body weight status of U.S. and Canadian women aged 19 years or older.
SOURCE: NHANES and CHMS.

and the majority of women have a BMI reflecting either overweight or obesity, reflecting excessive energy intake over a period of time. As discussed previously, it is possible that individuals within each body weight category could be weight stable, gaining weight, or losing weight, but the point prevalence provides useful information on overall energy adequacy for the group or population.

COMPARISON TO 2005 DRIS

To compare the EERs developed in this report to those established in the IOM report on macronutrients and energy (2002/2005), the committee made comparisons for reference U.S. male and female infants, children, and adults of median height and weight (as assessed in NHANES 2015–2018) using the 2023 and the 2005 EER equations. As shown in Figure 7-3, EERs for children under the age of 3 years were very similar. In older children (Figure 7-4) and adults (Figure 7-5), the most obvious difference appears to be the narrowing of the differences in energy requirements across PAL categories. In general, EERs of those in the least active PAL category are higher in 2023 than in 2005, while EERs of those in the highest PAL category are lower in 2023 than in 2005, and the increase from low active to active or active to very active tends to be smaller than in the previous EERs.

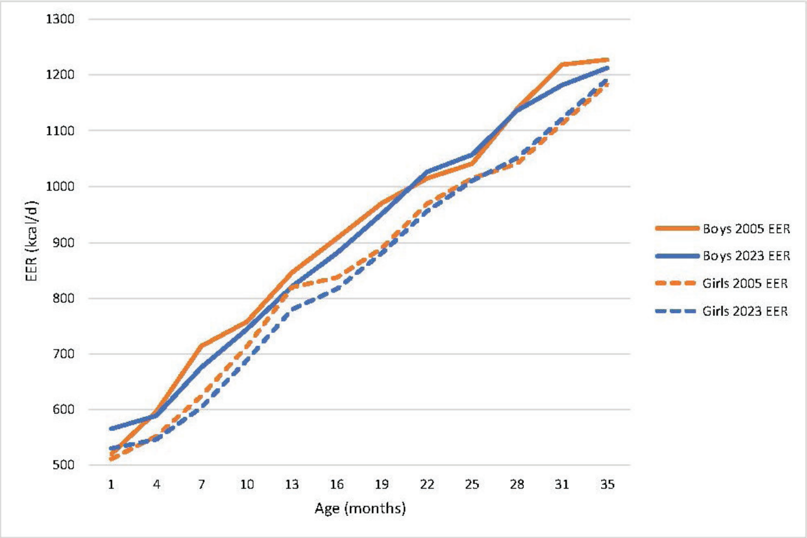

FIGURE 7-3 Comparison of EERs calculated using the 2005 and 2023 equations for boys and girls aged 1–35 months of median height and weight.
SOURCE: NHANES, 2015–2018.

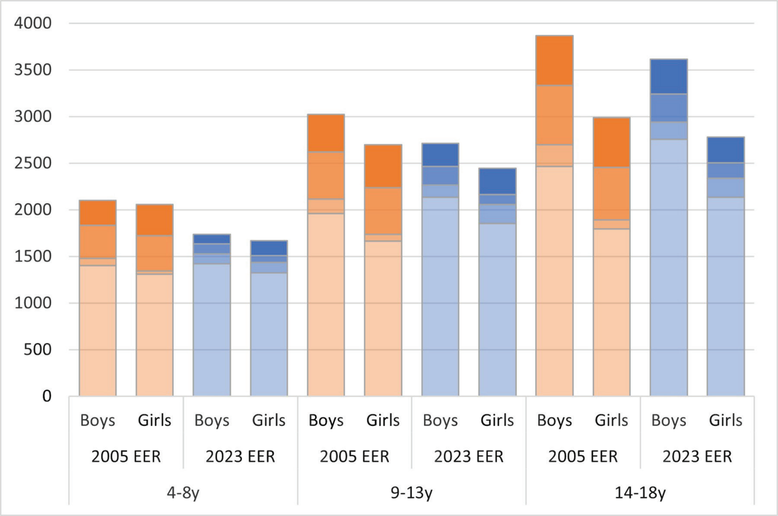

FIGURE 7-4 Comparison of EERs calculated using the 2005 and 2023 equations for boys and girls aged 4–18 years of median height and weight.
NOTE: Within each stacked bar, the bottom division (lightest shading) portrays the EER for inactive individuals, followed by EERs for low active, active, and very active individuals (at the top of the stacked bar and with the darkest shading).
SOURCE: NHANES, 2015–2018.

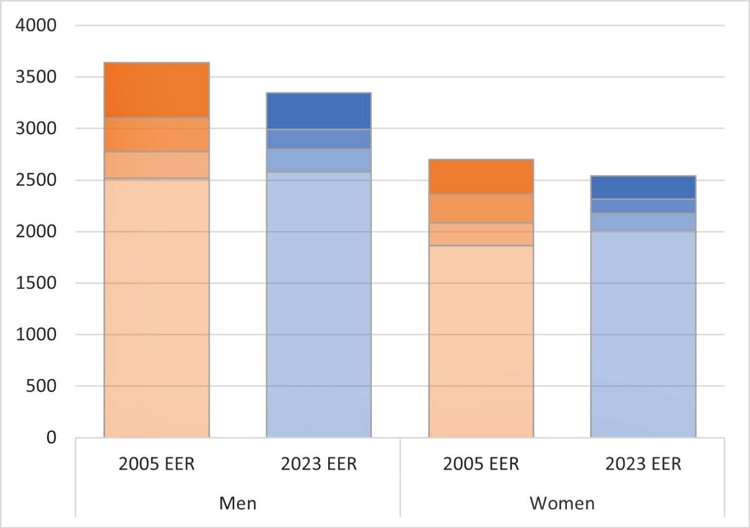

FIGURE 7-5 Comparison of EERs calculated using the 2005 and 2023 equations for men and women aged 19 years or older of median height and weight.
NOTE: Within each stacked bar, the bottom division (lightest shading) portrays the EER for inactive individuals, followed by EERs for low active, active, and very active individuals (at the top of the stacked bar and with the darkest shading).
SOURCE: NHANES, 2015–2018.

FINDINGS AND CONCLUSIONS

Findings

The committee finds that accurate determination of PAL category for individuals was extremely challenging, as the associations between PAL assessed by DLW and by readily accessible measures such as "steps" or physical activity questionnaires were generally weak. The new EERs developed for this report were very similar to the IOM (2002/2005) EERs for children under the age of 3 years. For older children and adults, the difference in the construction of PAL categories for the current EERs resulted in narrower difference across PAL categories, and a more consistent difference in energy requirements as the PAL categories increased, particularly for children.

Conclusions

The committee concludes that additional research to develop and validate measures to classify children and adults into PAL categories would improve *the application of the EER equations in practice. Use of the new EER equations is expected to lead to somewhat higher values for inactive individuals and lower values for very active individuals compared to the previous EER equations, but correct classification of individuals into PAL categories remains an important step of estimating energy requirements.*

REFERENCES

Basiotis, P. P., S. O. Welsh, F. J. Cronin, J. L. Kelsay, and W. Mertz. 1987. Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *Journal of Nutrition* 117(9):1638-1641.

Black, A. E., W. A. Coward, T. J. Cole, and A. M. Prentice. 1996. Human energy expenditure in affluent societies: An analysis of 574 doubly-labelled water measurements. *European Journal of Clinical Nutrition* 50(2):72-92.

Canadian Society for Exercise Physiology. 2021. *Canadian 24-hour movement guidelines: An integration of physical activity, sedentary behaviour, and sleep*. https://csepguidelines.ca/ (accessed November 25, 2022).

Craig, C. L., C. Cameron, J. M. Griffiths, and C. Tudor-Locke. 2010. Descriptive epidemiology of youth pedometer-determined physical activity: CANPLAY. *Medicine and Science in Sports and Exercise* 42(9):1639-1643.

DHHS (U.S. Department of Health and Human Services). 2018. *Physical activity guidelines for Americans*, 2nd ed. Washington, DC: U.S. Department of Health and Human Services.

Goldstein, R. F., S. K. Abell, S. Ranasinha, M. Misso, J. A. Boyle, M. H. Black, N. Li, G. Hu, F. Corrado, L. Rode, Y. J. Kim, M. Haugen, W. O. Song, M. H. Kim, A. Bogaerts, R. Devlieger, J. H. Chung, and H. J. Teede. 2017. Association of gestational weight gain with maternal and infant outcomes: A systematic review and meta-analysis. *JAMA* 317(21):2207-2225.

IOM (Institute of Medicine). 2000a. *Dietary Reference Intakes for vitamin C, vitamin E, selenium, and carotenoids*. Washington, DC: National Academy Press.

IOM. 2000b. *Dietary Reference Intakes: Applications in dietary assessment*. Washington, DC: National Academy Press.

IOM. 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press.

IOM. 2003. *Dietary Reference Intakes: Applications in dietary planning*. Washington, DC: The National Academies Press.

IOM and NRC (National Research Council). 2009. *Weight gain during pregnancy: Reexamining the guidelines*. Washington, DC: The National Academies Press.

Lovelady, C. 2011. Balancing exercise and food intake with lactation to promote post-partum weight loss. *Proceedings of the Nutrition Society* 70(2):181-184.

Park, J. H., K. Ishikawa-Takata, S. J. Lee, E. K. Kim, K. W. Lim, H. R. Kim, I. S. Lee, and S. Tanaka. 2016. Association between daily step counts and physical activity level among Korean elementary schoolchildren. *Journal of Exercise Nutrition and Biochemistry* 20(3):51-55.

Puyau, M. R., A. L. Adolph, F. A. Vohra, and N. F. Butte. 2002. Validation and calibration of physical activity monitors in children. *Obesity Research* 10(3):150-157.

Treuth, M. S., A. L. Adolph, and N. F. Butte. 1998. Energy expenditure in children predicted from heart rate and activity calibrated against respiration calorimetry. *American Journal of Physiology* 275(1):E12-E18.

Treuth, M. S., N. F. Butte, M. Puyau, and A. Adolph. 2000. Relations of parental obesity status to physical activity and fitness of prepubertal girls. *Pediatrics* 106(4):E49.

Treuth, M. S., A. L. Sunehag, L. M. Trautwein, D. M. Bier, M. W. Haymond, and N. F. Butte. 2003. Metabolic adaptation to high-fat and high-carbohydrate diets in children and adolescents. *American Journal of Clinical Nutrition* 77(2):479-489.

Tudor-Locke, C., J. J. McClain, T. L. Hart, S. B. Sisson, and T. L. Washington. 2009. Expected values for pedometer-determined physical activity in youth. *Research Quarterly for Exercise and Sport* 80(2):164-174.

Westerterp, K. R. 2018. Exercise, energy expenditure and energy balance, as measured with doubly labelled water. *Proceedings of the Nutrition Society* 77(1):4-10.

Wharton, S., D. C. W. Lau, M. Vallis, A. M. Sharma, L. Biertho, D. Campbell-Scherer, K. Adamo, A. Alberga, R. Bell, N. Boule, E. Boyling, J. Brown, B. Calam, C. Clarke, L. Crowshoe, D. Divalentino, M. Forhan, Y. Freedhoff, M. Gagner, S. Glazer, C. Grand, M. Green, M. Hahn, R. Hawa, R. Henderson, D. Hong, P. Hung, I. Janssen, K. Jacklin, C. Johnson-Stoklossa, A. Kemp, S. Kirk, J. Kuk, M. F. Langlois, S. Lear, A. McInnes, D. Macklin, L. Naji, P. Manjoo, M. P. Morin, K. Nerenberg, I. Patton, S. Pedersen, L. Pereira, H. Piccinini-Vallis, M. Poddar, P. Poirier, D. Prud'homme, X. R. Salas, C. Rueda-Clausen, S. Russell-Mayhew, J. Shiau, D. Sherifali, J. Sievenpiper, S. Sockalingam, V. Taylor, E. Toth, L. Twells, R. Tytus, S. Walji, L. Walker, and S. Wicklum. 2020. Obesity in adults: A clinical practice guideline. *CMAJ: Canadian Medical Association Journal* 192(31):E875-E891.

8

Risk Characterization and Public Health Implications

The Dietary Reference Intake (DRI) organizing framework includes a discussion of the public health implications of relationships between energy intakes that deviate from Estimated Energy Requirement (EER) values and adverse health outcomes, primarily a characterization of the risk of chronic diseases (see Chapter 2 for a description of the organizing framework). This framework also includes information on special vulnerable populations for whom the EER values may need to be adjusted.

In this chapter, evidence from published systematic reviews, augmented when appropriate with other relevant scientific publications, are summarized. Because of inaccuracies in reported energy intakes, this approach relies on indicators of energy intake imbalances as exposures for evaluating the risks of adverse health outcomes for studied age and sex groups, primarily from high-income countries. The following discussion summarizes evidence that the committee deemed most relevant to its task. The approach for selecting and evaluating published systematic reviews is described in Chapter 3, and additional detail is contained in Appendixes D, E, and F.

CHRONIC DISEASE RISKS ASSOCIATED WITH OVERWEIGHT AND OBESITY

Population data from Tables 6-5 and 6-6 in Chapter 6 show a high prevalence of overweight and obesity in U.S. and Canadian populations. To maintain body weight over time, energy intake must equal energy expenditure. If energy intake exceeds energy expenditure, weight gain will result. Questionnaire data from the U.S. National Health and Nutrition Examination Survey (NHANES) indicate a significant prevalence of attempts by study participants to lose weight currently or in the past year: 10 percent for normal weight males 19 years or older and 27 percent for adult women. Among overweight adults, the percentage is 32 percent for adult males and 47 percent for adult females. Higher percentages are observed for obese adults: 44 percent for males and 50 percent for females (see Appendix Tables L-15, L-16, and L-17). Thus, not only are the prevalence of overweight and obesity high among the U.S. and Canadian populations, but the NHANES data also indicate a relatively high prevalence of trying to lose weight. To evaluate the associations between weight gain or obesity and the risk of chronic diseases, the committee relied on measures of body weight and adiposity as indicators of exposures rather than on self-reported dietary intakes because of significant inaccuracies in the reporting of actual energy intakes.

People who have overweight or obesity are more prevalent in the United States and Canada compared to those who are underweight; however, self-reported dietary intakes are an inaccurate indicator of actual energy intakes, and body weight is reflective of past energy imbalance states. Nevertheless, body weight is frequently used as the exposure that best indicates a state of energy imbalance.

The committee carried out an umbrella review (described in Chapter 3) of published systematic reviews to evaluate associations of body mass index (BMI), weight change, and weight cycling with the risk of several chronic disease outcomes and all-cause mortality. Three exposure measures were used as indicators of deviations from meeting energy requirements to achieve energy balance: the effect of BMI, the effect of weight change, and the effect of weight cycling. The umbrella review served as the committee's primary data source. For topics for which no existing systematic reviews were identified and the committee considered to be high priority, the umbrella review was supplemented with relevant longitudinal or population-based studies from peer-reviewed published literature. Outcomes included hypertension and cardiovascular disease and mortality, some cancers, all-cause mortality, and diabetes. Appendix J presents tabulated summaries of the number of studies within the systematic review, participant characteristics, study designs, methods used, exposures, and outcomes extracted from the literature discussed below.

Body Mass Index and Body Composition

In both clinical and community settings, calculation of body mass index (BMI; defined as weight in kilograms divided by the square of height in meters) remains the easiest and most readily accessible tool for identifying individuals at risk of adverse health outcomes related to being overweight or underweight (Gonzalez et al., 2017). BMI is an insensitive measure, however, because it assumes that an optimal weight range exists, regardless of the proportion of fat to fat-free mass. Many more sophisticated methods, compared to the calculation of BMI, are available to measure fat and fat-free mass precisely and reliably, including bioelectric impedance, ultrasound, and imaging modalities such as dual energy x-ray absorptiometry, computed tomography, and magnetic resonance. However, these techniques are primarily used in research settings. The most frequently stated limitation of BMI is that individuals with a high lean body mass (i.e., skeletal muscle) might have a high BMI without having excess body fat. Moreover, BMI does not account for interindividual variability by age, sex, ethnicity, or health status (Pasco et al., 2012).

Anthropometric techniques, such as waist circumference, waist–hip ratio, and waist–height ratio offer the potential to better discriminate cardiometabolic risk than BMI (Darbandi et al., 2020). Nonetheless, BMI has continued to be used as a proxy for adiposity and chronic disease risk since the original publication of BMI classifications by the World Health Organization (WHO).

BMI Categories

The National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC) guidelines use the original cutoffs identified by WHO to define adult individuals as having underweight (BMI < 18.5), normal weight (BMI 18.5–24.9), overweight (BMI 25.0–29.9), or obesity (≥ 30). A 2006 update of the WHO classifications included categories to identify severe underweight (< 16.5) and to further define obesity risk as class I (BMI 30.0–34.9), class II (BMI 35.0–39.9) and class III (≥ 40.0) in adults (WHO, 2016a).

Strong evidence has demonstrated that the WHO cutoffs underestimate obesity-related health risk in Asian adults. For example, the China Health and Nutrition Survey identified a lower threshold for overweight in the BMI range of 22.5 to 25.9 for males and 22.8 to 26.6 for females (He et al., 2015). Consequently, more recent cutoffs have been adjusted to a BMI of 23–24.9 for overweight and BMI ≥ 25 for obesity in Asian populations (Weir and Jan, 2022).

Additional adjustment in BMI classification may be needed for older adults. The Canadian Longitudinal Study on Aging identified age-specific BMI thresholds for older adults that are associated with cardiometabolic health outcomes. This study also compared the performance of these thresholds against the WHO BMI cutoffs for comparable age groups.

Findings indicated that for adults 65 years and older, the BMI threshold should be higher than the WHO cutoffs, with overweight defined at a BMI of 26.9 in adults aged 65 to 74 years and 26.6 in adults ≥ 75 years (Javed et al., 2022).

BMI cutoffs for children and adolescents are identified by percentiles or Z-scores based on sex and age group. Some evidence indicates a need for a better approach to defining BMI cutoffs in children and adolescents based on ethnicity. For example, a study in Indian (South Asian descent) and Creole (African/Madagascar descent) children aged 7 to 13 years conducted in Mauritius showed that when matched by BMI, Indian children had a higher percentage of body fat than Creole children. This finding suggests that the WHO BMI cutoffs for overweight and obesity would need to be lowered by 4.6 to 5.9 units in Indian and 2.0 to 3.7 units in Creole children (Ramuth et al., 2020).

BMI and Chronic Disease Risk

Prevalence of high BMI has reached epidemic proportions worldwide. Numerous studies have shown a strong linear relationship between high BMI and an increased risk for chronic disease. Although risk for some chronic disease states, such as cardiovascular diseases, may be better predicted by waist circumference, waist–hip ratio, or waist–height ratio, the body of evidence based on systematic reviews, meta-analysis, and Mendelian randomization indicate a profound relationship between high BMI and functional disabilities, impaired quality of life, serious disease states, and mortality.

Diabetes

Evidence from systematic reviews A systematic review by Zhang et al. (2021) found that prepregnancy BMI ≥ 25.0 increases risk 2.64-fold for having gestational diabetes. Further, during pregnancy, every additional 5 units in BMI was associated with a 10 percent increased risk for type 1 diabetes (Hidayat et al., 2019). This relationship between high BMI during pregnancy and type 1 diabetes was nonlinear, such that a steeper increase in risk occurs with BMI ≥ 26.0. In children, a high BMI was shown to increase the risk for childhood and adolescent asthma, prediabetes, hypertension, and nonalcoholic fatty liver disease (NAFLD) (Azizpour et al., 2018; Sharma et al., 2019). Children and adolescents with a BMI equal to or greater than the 85th percentile compared to those who have normal or underweight have a 64 to 92 percent increased risk for asthma, a 40 percent increased risk for prediabetes, a 4.4-fold increased risk for hypertension, and a 26-fold increased risk for NAFLD.

Among young and middle-aged adults, having a BMI ≥ 25.0 is associated with the risk of numerous chronic disease conditions. Yu et al. (2022) conducted a systematic review for associations between underweight and type 2 diabetes and between weight status and prediabetes. The review included prospective cohort studies with a minimum 12-month follow-up period. The primary analyses of diabetes risk were performed using the Asian versus non-Asian BMI classifications with additional analyses for risk of prediabetes or type 2 diabetes. The analyses found that overweight and obesity were associated with a 24 percent increased risk for prediabetes, while overweight was associated with a 2-fold increased risk and obesity a 4.5-fold increased risk for type 2 diabetes.

A systematic review to determine whether associations exist between sarcopenic obesity and risk of type 2 diabetes in adults with overweight and obesity found a 38 percent increased risk for type 2 diabetes among those with sarcopenic (compared to nonsarcopenic) obesity (Khadra et al., 2019).

Larsson and Burgess (2021) reviewed evidence for a causal association between BMI and chronic diseases. A meta-analysis of mendelian randomization (genetically predicted BMI in relation to chronic disease) studies showed a high adult BMI as a causal risk factor for a number of chronic diseases, in particular type 2 diabetes, which showed a 2-fold increased risk with a BMI ≥ 25.

Evidence from peer-reviewed literature In a longitudinal analysis of 1,168,418 women using Behavioral Risk Factor Surveillance System (BRFSS) 2006–2010 survey data, Ibe and Smith (2014) assessed population-level changes in the prevalence of diabetes among women with no known risk factors and the influence of those changes on diabetes-related outcomes. In the study population of 18- to 64-year-old women, after adjusting for age, race, physical activity, and year of survey response, the analysis indicated a 3.5-fold increase in diabetes in those with a BMI > 25. There was also an approximately 30 percent projected increase in odds of diabetes diagnoses for this population in the subsequent 10 years.

Hypertension and Cardiovascular Disease (CVD)

Evidence from systematic reviews A systematic review by Jayedi et al. (2018) analyzed 57 prospective cohort studies for associations between anthropometric measures and risk of developing hypertension. Studies that reported risk estimates of hypertension for three or more quantitative categories of indices of general and abdominal adiposity were included in the review. Overall, the review found that each 5-unit increase in BMI above 20.0 was associated with a 49 percent increased risk of hypertension.

Zhou et al. (2018) conducted an intake–response meta-analysis of 57 cohort studies examining the relationship between multiple adiposity measures and incidence of hypertension. The study included 125,071 incident cases among 830,685 participants. Results of the meta-analysis found at least a 50 percent increase in the risk for hypertension for every 5-unit increase in BMI, suggesting that in the normal range of BMI values, leanness may contribute to preventing hypertension incidence.

Liu et al. (2018b) carried out a systematic review and meta-analysis of prospective studies to understand the strength and shape of the intake–response relationship between BMI and the risk of stroke. This review found that the risk of stroke increases by 10 percent for every 5-unit increase in BMI for those with a BMI > 23 to 24, but not for those with lower BMIs, and the risk was greater for males than for females

In a systematic review and meta-analysis, Dugani et al. (2021) evaluated the magnitude of associations between various risk factors and premature myocardial infarction (MI) in males and females aged 18 to 65 years. Among the findings were that males with overweight or obesity have an almost 2-fold increased risk for premature myocardial infarction. Other systematic reviews for the risk of CVD found that waist circumference or waist–height ratio were better predictors of risk than BMI. Darbandi et al. (2020) found that BMI, waist circumference, and waist–height ratio have moderate power to identify a risk for CVD and that in adults, waist circumference and waist–height ratio were better predictors of CVD than BMI. In a review of mendelian randomization studies, Kim et al. (2021) showed high BMI as a causal risk factor for CVD outcomes. Specifically, each 5-unit increase in BMI increased risk for CVD events.

Evidence from peer-reviewed published literature In a prospective cohort study, Rexrode et al. (2001) compared waist circumference and waist–height ratio as predictors of coronary heart disease (CHD) and to determine if there was an association with disease independent of BMI in over 20,000 men participating in the Physicians' Health Study. The study found that among men with a BMI ≥ 27.6, there was a 73 percent increased risk for a CHD event, suggesting an association between abdominal adiposity and elevated risk of CHD in middle-aged and older men.

A cohort of 5,209 Framingham Heart Study participants were examined for a relationship between BMI and morbidity and mortality from CHD (Kim et al., 2000). In this 24-year follow-up study, the relative risk for CHD among male participants was found to be 28 percent for BMI ≥ 23.8, 45 percent for BMI ≥ 25.9, and 53 percent for BMI ≥ 28.2. Among female participants, risk of CHD-related death was 86 percent higher for BMI > 27.61 compared to BMI < 22.34.

A community longitudinal study to assess risk for diabetes or CVD stratified by BMI and the presence or absence of metabolic syndrome or insulin resistance found that 2,902 females and males with BMI ≥ 25.0 had a 3-fold increased risk for CVD. Taken together, risk factor clustering or insulin resistance appeared to confer much of the risk for diabetes or CVD commonly associated with high BMI (Meigs et al., 2006). Another community-based longitudinal study of 2,316 males with type 2 diabetes and BMI ≥ 25.0 assessed their risk of CVD and mortality and found that males with overweight and obesity with diabetes have a similar 2.7-fold increased risk (Church et al., 2005).

Cancers

Evidence from systematic reviews Sohn et al. (2021) examined the risk of hepatocellular cancer in a systematic review of studies of men and women 18 years and older with a BMI ≥ 25.0. This review found that the risk for liver cancer increased in a BMI-dependent manner, with a 36 percent increased risk for BMI > 25, 77 percent increased risk for BMI > 30, and 3-fold increased risk for BMI > 35 (and a 70 percent increased risk of hepatocellular cancer overall for BMI ≥ 25).

Premenopausal and postmenopausal breast, endometrial, and ovarian cancer risk among women was assessed based on their early-life (age ≤ 25 years) BMI in a systematic review by Byun et al. (2022). Across 37 studies that included 1.8 million women each 5-unit increase in early-life BMI was associated with a 16 percent reduced breast cancer risk in premenopausal and postmenopausal women. Across 10 studies that included 662,779, each 5-unit increase in early-life BMI was associated with a 1.4-fold increased endometrial cancer risk. Across six studies that included 496,391 participants, each 5-unit in BMI increase in early life was associated with a 15 percent increased ovarian cancer risk.

A systematic review of 28 prospective cohort studies, with 28,784,269 participants and 127,161 lung cancer cases, examined associations between BMI and lung cancer risk. The review found that higher BMI was associated with lower lung cancer risk overall, but that multiple confounders, including smoking, preclinical cancer, and time lag affected the association. Furthermore, in contrast, highest category waist circumference (versus lowest category) was associated with 26 percent increased lung cancer risk (Gao et al., 2019).

Gu et al. (2022) searched previously published systematic reviews and meta-analyses of cohort studies to identify potential risk factors for prostate cancer. A two-sample mendelian randomization analysis was used to validate potentially causal relationships. This study found that higher

BMI was associated with a 1 percent decreased risk for localized prostate cancer, consistent with previous mendelian randomization studies.

A meta-analysis by Hidayat et al. (2018) identified associations between anthropometric factors and non-Hodgkin's lymphoma. Among more than 7 million males and females aged 18 years and older, each 5-unit increase in BMI was associated with a 6 percent increased risk for non-Hodgkin's lymphoma, with no difference by sex. Further, each 5-unit increase in BMI in early adulthood (18–21 years) was associated with an 11 percent increased risk for non-Hodgkin's lymphoma.

Liu et al. (2018a) conducted a meta-analysis of 24 cohort studies with almost 9 million participants to examine associations between BMI and kidney cancer risk in males and females aged 18 years and older and with a BMI > 20. An increased kidney cancer risk of 1.06 (95% CI, 1.05–1.06) for each 1-unit increase in BMI > 20 was found in this intake–response meta-analysis.

A systematic review of an overlapping set of epidemiological studies on the association of BMI with early-onset colorectal cancer risk was conducted in males and females aged less than 55 years old with BMI ≥ 25.0 (Li et al., 2021). Both overweight and obesity were associated with a 42 percent increased risk of early-onset colorectal cancer. O'Sullivan et al. (2021) conducted a systematic literature review of studies examining nongenetic risk factors for early-onset colorectal cancer in adults aged less than 50 years old. Obesity (BMI ≥ 30) was associated with a 54 percent increased risk of early onset colorectal cancer, with males at higher risk than females.

Li et al. (2016) examined BMI and gallbladder cancer risk in a systematic review of more than 9 million individuals aged 18 years and older with a BMI of 25.0 or greater. The pooled risk for gallbladder cancer for overweight was 10 percent and obesity 58 percent, and the risk of gallbladder cancer increased by 4 percent for each 1-unit increase in BMI.

Youssef et al. (2021) conducted a systematic review to evaluate the effect of BMI and weight change over time on the risk of developing thyroid cancer. The study included more than 24 million individuals aged 18 years and older with BMI < 18.5 or ≥ 25.0. The analysis found a 26 and 50 percent, respectively, increased risk of thyroid cancer associated with overweight and obesity, with the risk greater in females than in males. Having an underweight BMI decreased risk by 32 percent.

Disability

Evidence from systematic reviews Jiang et al. (2019) conducted a systematic review and intake–response meta-analysis of 37 studies on all-cause mortality and 9 on disability to examine associations between BMI and disability in adults aged 65 years and older. The study found that a BMI of 24.0 to 28.0 decreased risk for disability by 4 percent, but BMI > 28 increased disability risk by 19 percent. Mortensen et al. (2021) carried out a systematic review to assess various modifiable risk factors for hip fracture. BMI < 18.5 was associated with almost a 3-fold increased risk for fragility hip fracture, whereas a BMI > 30 decreased hip fracture risk by, on average, 42 percent.

All-Cause Mortality

Evidence from systematic reviews In addition to assessing the risk of hip fracture, Jiang et al. (2019) examined all-cause mortality. Adults aged 65 years and older with BMI < 23.0 and > 33.0 had increased risk for all-cause mortality. Kitahara et al. (2014) estimated sex- and age-adjusted total and cause-specific mortality rates and multivariable-adjusted hazard ratios across 20 prospective studies for adults aged 19 to 83 years at baseline. The study found that, compared with lower BMI (18.5–24.9), adults with a BMI of 40 or higher had incrementally increased risks for death (adjusted hazard ratios ranging from 2.25 to 5.91). The increased risks of death with higher BMI were somewhat greater for males than for females.

Weight Change and Chronic Disease Risk

Studies designed to evaluate the relationships of body weight and the risk of adverse health outcomes often use baseline measures of weight and BMI. Several investigators have suggested that weight gain based on weight measures at both baseline and study completion could be a better approach for evaluating the relationship of obesity and adverse outcomes because it would reflect changes over time rather than rely on a single point estimate of weight. To evaluate these relationships, the umbrella review process was used to identify relevant systematic reviews published during or after 2017 (see Appendix J for summaries of extracted data and Appendix E for eligibility criteria).

Weight Gain

Evidence from systematic reviews The committee identified seven systematic reviews on weight gain and the risk of chronic disease; all were based on observational studies (Alharbi et al., 2021; Chan et al., 2019; Hao et al., 2021; Karahalios et al., 2017; Jayedi et al., 2018, 2020; Sun et al., 2021). Quality ratings ranged from "partially well done" to "well done" (see Appendix J).

Weight gain and risk of all-cause mortality was evaluated in two systematic reviews (Alharbi et al., 2021; Karahalios et al., 2017). Given the likelihood that weight gain in middle-aged to older adults is more likely to involve decreases in muscle mass and increases in abdominal adiposity as compared to younger adults, both systematic reviews selected studies with populations of middle-aged or older adults. Karahalios et al. (2017) evaluated weight gain in healthy adults aged 40–65 years. Subgroup analyses of 18 studies in which baseline and follow-up weights were measured rather than self-reported did not find a significant association between weight gain and risk of all-cause-mortality (hazard ratio [HR], 1.04; 95% CI, 0.97–1.12). In other analyses where measured and self-reported weight gain were combined, high heterogeneity of results was explained in part by the inclusion of studies with self-reported weight measures.

Alharbi et al. (2021) evaluated the effect of weight change in community-dwelling adults aged 65 years and older. Studies in which weight gain was either self-reported or measured were combined. The study found a small but significant association between weight gain and all-cause mortality (HR, 1.10; 95% CI, 1.02–1.17).

Weight Gain and CVD

The association between weight gain and CVD mortality was evaluated in two systematic reviews (Jayedi et al., 2020; Karahalios et al., 2017). When meta-analyses were conducted in a subsample of 50- to 65-year-old adults in which baseline and follow-up weights were measured rather than self-reported, investigators found that weight gain was not significantly associated with the risk of CVD mortality (HR, 1.14; 95% CI, 0.97–1.35) (Karahalios et al., 2017). The systematic review by Jayedi et al. (2020) included adults 18 years and older. The included studies contained a mixture of measured and self-reported weight gains. Results of the analysis showed an 11 percent higher risk of CVD mortality associated with a 5-kg weight gain during adulthood (relative risk [RR], 1.11; 95% CI, 1.04–1.19). In subgroup analyses, significant associations were observed only with a follow-up duration of 10 or more years, when participants had a mean age less than 65 years, and with exclusion of participants with preexisting CVD.

Weight gain and CVD incidence was evaluated in two systematic reviews (Jayedi et al., 2020; Sun et al., 2021). Jayedi et al. (2020) included studies of adults 18 years and older. Reported weight gains reflected unintentional increases in weight during adulthood. Two of the selected studies reported on weight gain and the risk of CVD incidence. Results indicated that a 12 percent higher risk of CVD incidence was associated with a 5-kg increment in weight (RR, 1.12; 95% CI, 1.10–1.13). Sun et al.

(2021) evaluated associations between weight changes from childhood to adulthood and the onset of CVD in adulthood. The reference group had normal weight during both childhood and adulthood. The study found no association between weight and the onset of CVD for the group that had excess weight during childhood but normal weight during adulthood (odds ratio [OR], 1.22; 95% CI, 0.92–1.62). Among participants with normal childhood weights but excessive adult weights, the results indicated a significantly increased risk of CVD during adulthood (OR, 2.76; 95% CI, 1.79–4.27). For the group in which excess weights occurred during both childhood and adulthood, the risk of CVD was also significantly increased (OR, 3.04; 95% CI, 1.69–5.46).

Weight Gain and Hypertension

Weight gain and hypertension were evaluated in two systematic reviews (Jayedi et al., 2018; Sun et al., 2021). Jayedi et al. (2018) included studies with participants aged 18 years and older from the general population and had a follow-up duration of more than 1 year. Hypertension was significantly associated with adult weight gain equal to a 1-unit increase in BMI (RR, 1.16; 95% CI, 1.09–1.23). With weight gain, men exhibited a slightly higher incidence of hypertension (RR, 1.20; 95% CI, 1.05–1.36) than women (RR: 1.13; 95% CI, 1.04–1.22). Sun et al. (2021) evaluated associations between childhood to adulthood weight changes and the risk of hypertension. There was no association with hypertension when childhood weight was characterized as excessive and adult weight was normal (OR, 1.25; 95% CI, 0.73–2.13). Normal weight in childhood followed by excessive weight in adulthood, however, was associated with an increased risk in hypertension (OR, 2.69; 95% CI, 2.07–3.49). Excess weight in both childhood and adulthood resulted in a stronger relationship with hypertension (OR, 3.49; 95% CI, 2.21–5.50).

Weight Gain and Cancer

Weight gain and cancer mortality was evaluated in one systematic review (Karahalios et al., 2017). The investigators included studies in which healthy participants were between age 40 and 65 years and follow-up from baseline was at least 5 years. The largest weight gain was compared to a reference group. The association between weight gain and cancer mortality was not significant (HR, 1.04; 95% CI, 0.96–1.13). Higher hazard ratios were observed in studies that used self-reported weight values rather than measured values. It is possible that the duration of the follow-up period may have been too short to detect many cancers.

Weight gain and breast cancer was evaluated in two systematic reviews by Chan et al. (2019) and Hao et al. (2021). The Chan et al. (2019) review evaluated weight gain in 5-kg increments from 18 years to study baseline in both premenopausal and postmenopausal women. Changes in adiposity were assessed by BMI, waist circumference, or waist–hip ratio. There was no association between weight gain and breast cancer risk for premenopausal women (RR, 1.00; 95% CI, 0.97–1.03). The association for postmenopausal women was significant (RR, 1.07; 95% CI, 1.05–1.09). There was a significant association between weight gain per 5-kg increase and estrogen receptors and progesterone receptors (ER+PR+) breast cancers (RR, 1.11; 95% CI, 1.06–1.17), but not with ER–PR– or ER+PR– breast cancers (RR, 1.02; 95% CI, 1.00–1.05 and RR, 0.99; 95% CI, 0.97–1.02, respectively).

When Chan et al. (2019) evaluated associations between use of menopausal hormones and risk of breast cancer among postmenopausal women experiencing weight gains, they observed positive associations between hormone "never use," "never/former use," and "ever use" (RR, 1.06, 95% CI, 1.03–1.09; RR, 1.09, 95% CI, 1.07–1.12; and RR, 1.08, 95% CI, 1.16, respectively). There was no association between "current" hormone use and breast cancer (RR, 1.00, 95% CI, 0.98–1.03). Adiposity and weight gain were consistently associated with risk of breast cancer regardless of whether adiposity was measured with BMI, waist circumference, or waist–hip ratio.

Hao et al. (2021) evaluated the association between weight gain and incident breast cancer risk across different menopause stages. A significant association between weight gain and breast cancer risk was not observed for premenopausal women (RR, 1.00; 95% CI, 0.83–1.21), but such risk was observed in postmenopausal women (RR, 1.55; 95% CI, 1.40–1.71). An intake–response association for postmenopausal women for a 5-kg increase in weight gain was significant (RR, 1.08; 95% CI, 1.07–1.09). In comparing highest weight gain to lowest weight gain categories in women after menopause, there was an increased risk of postmenopausal breast cancer (RR, 1.59; 95% CI, 1.23–2.05).

Weight Gain and Diabetes

Sun et al. (2021) investigated weight gain and the risk of type 2 diabetes by comparing associations between weight status in childhood and adulthood. Compared to normal weight during both childhood and adulthood (the reference group), significant associations with risk of type 2 diabetes were observed with all other groups. For the group with excessive weight in childhood but normal weight in adulthood, the OR was 1.37 (95% CI, 1.10–1.70). For the group with normal weight during childhood and excess weight in adulthood, the OR was 3.40 (95% CI, 2.71–4.25). For the group in which excess weight occurred during both childhood and adulthood, the OR was 3.94 (95% CI, 3.05–5.08).

Weight Cycling

Twenty to 55 percent of adults with overweight or obesity have a history of weight cycling, a common occurrence in individuals who seek treatment to lose weight (Rhee, 2017). The range of consequences of weight cycling on health outcomes, however, has yet to be clarified. As discussed below, repeated cycles of weight loss and regain have been shown to promote greater subsequent or future weight gain and this has been hypothesized to occur through the process of adaptive thermogenesis or energy compensation and thus may predispose an individual to greater obesity or increased adiposity as a consequence. Long-term obesity is a concern because of the public health implications, such as predisposition to risk of cardiometabolic health outcomes.

Definition of Weight Cycling

The terminology and definitions used to describe weight cycling vary. Examples include weight cycling, yo-yo dieting, weight fluctuation, and obesity relapse. At present, no standardized definition for weight cycling exists with regard to period of time, number of cycles, and amount of weight change to qualify as a weight cycle. Further, limited evidence exists for the effects of weight cycling on energy expenditure in humans. The committees' search for relevant evidence found no systematic reviews, except for one study that used doubly labeled water (DLW) measures and five studies that used indirect calorimetry to determine resting energy expenditure (REE).

Weight Cycling and Health Outcomes

Evidence from systematic reviews A systematic review by Alharbi et al. (2021) investigated the association between weight cycling and mortality. The review included four studies with 6,901 participants and showed that weight cycling was associated with a 63 percent increased risk for all-cause mortality.

A systematic review by Zou et al. (2021) examined associations between weight cycling and risk of diabetes. The review included 14 studies with 253,766 participants. Across studies, those with diabetes events and weight cycling had a 23 percent increased risk for type 2 diabetes. However, an association between weight cycling and the risk of diabetes was not found among participants with obesity.

Zhang et al. (2019) conducted a systematic review to identify reports of intentional weight loss, weight cycling after intentional weight loss, bariatric surgery, and endometrial cancer risk. The review included four studies of weight cycling with 92,063 participants among which 3,485 cases of endometrial cancer occurred. Among the four studies, weight cycling was reported to be associated with between 1.23 and 2.33 times increased risks for endometrial cancer.

Zou et al. (2019) evaluated associations between body weight fluctuation and risk of mortality and CVD in a systematic review of 23 studies with 441,199 participants. The review found that weight cycling increased risk for all-cause mortality by 41 percent and risk for CVD mortality by 36 percent.

Evidence from peer-reviewed published literature El Ghoch et al. (2018) examined the effect of intentional cycling with weight loss and weight regain on energy expenditure, body composition, cardiovascular risk factors, and psychosocial variables in patients with severe obesity. Clinical and psychosocial variables were measured in 38 adults with class III obesity. Participants in the study had been readmitted to a residential treatment program for severe obesity after a cycle of weight loss and regain compared with those logged at a prior admission. The study found no significant changes in REE between the readmitted and prior admission groups. Younger participants and participants with higher historical weight were found to be more likely to regain additional weight.

Fothergill et al. (2016) examined participants from "The Biggest Loser" competition for long-term changes in resting metabolic rate (RMR) and body composition related to weight cycling. RMR and body composition measurements were ascertained from dual energy X-ray absorptiometry during a 3-day inpatient stay. RMR was determined at three points: baseline, following the 30-week Biggest Loser competition, and 6 years after the competition. REE remained significantly below baseline by 704 ± 427 SD kcal/d; total energy expenditure (TEE) by DLW also remained significantly reduced, by 499 ± 207 kcal/d. Although participants experienced significant overall weight regain in the 6 years following the weight loss competition, their RMR remained suppressed at the same average level found at the end of the competition.

Another study of weight cyclers examined the effect of intentional weight loss and obesity classes I and II. Weight-cycling and weight-stable participants were examined at baseline, immediately following weight loss, and at 6 months of follow-up. The study found that weight regain was incomplete and accounted for 83 and 42 percent of total weight loss in female and male participants, respectively. Additionally, regain in total fat and adipose tissue depots was proportional to weight regain, except for a higher regain in extremity and a lower regain in extremity and visceral adipose tissue in female and male participants, respectively. Overall, REE (adjusted for organ and tissue masses) was significantly reduced in weight-cycling compared to weight-stable participants, suggesting that weight loss–associated adaptations in REE could negatively affect weight loss as well as contribute to weight regain (Bosy-Westphal et al., 2013).

Intentional Weight Loss and Chronic Disease Outcomes

Evidence from Systematic Reviews

Ma et al. (2017) conducted a systematic review of randomized controlled trials to examine the effect of intentional weight reduction on all-cause, cardiovascular, and cancer mortality; CVD; cancer; and body weight for adults with obesity. The study found high-quality evidence that intentional weight reduction in adults with obesity was associated with an 18 percent relative reduction in premature mortality over a median trial duration of 2 years. In addition, the investigators identified evidence indicating that physical activity as an adjunct to weight reduction could enhance the effectiveness of dietary intervention.

LeBlanc et al. (2018) reviewed the evidence on the benefits and harms associated with behavioral and therapeutic weight loss and weight loss maintenance interventions in adults. The study found that, compared to control conditions, behavior-based interventions were associated with more weight loss and that maintenance interventions were associated with less weight regain over the study periods of 12 to 18 months.

Authoritative Reports on Obesity and Chronic Disease Risk

In addition to the scientific literature, numerous agencies have published reports on the association between obesity and the risk of chronic disease. These reports have found that obesity is associated with an increased risk of some cancers, diabetes, and cardiovascular disease (EFSA, 2013; SACN, 2011; Powell-Wiley et al., 2021; WCRF/AICR, 2018; Lauby-Secretan et al., 2016; WHO, 2016b, 2021, 2022).

CONSIDERATIONS FOR INDIVIDUALS WITH SPECIAL NEEDS

Information obtained from DLW databases used in this report does not include data from individuals with acute or chronic diseases; those with critical illnesses such as burns or sepsis or those on mechanical ventilation; those undergoing bariatric procedures; those taking medications that alter energy requirements; or those with physical activity levels greater than 2.5. Therefore, the EER equations developed do not take into account estimates of the additional energy that may be expended or stored under these conditions. In cases such as these, modification of the EER equation (based on an individual's sex, age, height, weight, and PAL) or use of an alternative prediction equation would be needed for the individual to optimize accuracy in determining energy requirements. This is especially important because long-term energy imbalance, whether positive or negative, can lead to adverse outcomes ranging from comorbidities to mortality.

Considerations When Applying the EER May Overestimate Needs

Bariatric Surgery

A systematic review of 30 studies that included 1,233 patients showed that REE and TEE were significantly reduced from baseline as late as 12 months after bariatric surgeries. Notably, this review also showed that REE prediction equations overestimated REE after weight loss (Li et al., 2019).

Medications

Evidence from systematic reviews Whereas the effects of many medications on energy expenditure are unknown, a systematic review of 33 studies showed that continuous sedation or analgesia used in intensive care reduces energy expenditure as measured by indirect calorimetry (Dickerson and Roth-Yousey, 2005). Acute or chronic administration of cardiovascular-adrenergic receptor antagonism agents, such as propranolol and atenolol, have also been shown to reduce REE by as much as 12 percent. As body fat depots can affect the systemic distribution of pharmaceutical agents, persons with excess adiposity may experience different effects.

A systematic review of 16 studies with a total of 267 patients assessed the effect of chemotherapy on REE measured by indirect calorimetry (Van Soom et al., 2020). The findings confirmed underestimation of REE with use of the Harris-Benedict equation for all cancer types studied. A significant decrease in REE was shown in lung cancer and non-Hodgkin's lymphoma. Regardless of type or stage of cancer or chemotherapeutic agent, REE showed a U-shaped curve with an increase upon start of treatment, decrease during treatment, and increase at treatment end.

Evidence from peer-reviewed published literature A variety of endocrine and cardiometabolic agents have been assessed for effects on energy expenditure, but mechanisms driving effects on energy balance remain unclear. Antihyperglycemic agents used in treatment of type 2 diabetes can promote weight gain or loss (Apovian et al., 2019). While all types of insulin therapy are associated with weight gain, the effects differ by drug and regimen. Weight gain is also common with newer antiretroviral regimens for treatment of human immunodeficiency virus (HIV) infection, such as integrase strand transfer inhibitors (Bourgi et al., 2020).

Potential for Underestimating Energy Needs

As energy intake in excess of expenditure is increasingly occurring in the general population, undernutrition or inadequate energy intake remains a problem in some population subgroups. A chronic state of energy deficit promotes mobilization of energy stores, resulting in the loss of body mass and altered body composition. The effects of chronic undernutrition include low growth rate (stunting) and impaired bone accretion in children, susceptibility to infections, immune system vulnerability, and impaired wound healing.

Critical Illness

A systematic review of 103 articles that included 4,388 adults, children, and neonates showed that several physiological and clinical factors influencing energy expenditure are not included in predictive equations. Among critically ill hospitalized patients, energy imbalance is associated with mortality (McClave et al., 2016). Further, more accurate estimation of energy requirements can be measured by indirect calorimetry rather than by using the EER prediction equations (Boullata et al., 2007; Oshima et al., 2016).

Protein–Energy Malnutrition States

Similar to critical illness, in several other biological states where protein energy wasting or hypercatabolism occur—such as chronic kidney disease, advanced stage cancer, untreated HIV, chronic obstructive pulmonary disease, and congestive heart failure—the loss of energy stores leads to cachexia, a metabolic syndrome characterized by loss of muscle mass with or without loss of fat mass (Evans et al., 2008). Further, loss of muscle mass combined with loss of muscle strength and performance (power and function), termed sarcopenia, may also alter energy requirements. Sarcopenia is associated with aging and disease processes and is also widely prevalent in the state of obesity in most life stages. A systematic review of 18 studies showed a prevalence of sarcopenic obesity in 29 to 33 percent of boys and 20 to 39 percent of girls aged 6 to 19 years (Zembura and Matusik, 2022).

Individuals with Extremely High Physical Activity Levels

For the general population, a physical activity level (PAL) value of 2.5 represents the upper limit of sustained metabolic rate over periods sufficiently long that body mass remains constant. Athletes (those engaged in intense, extreme endurance activities) can obtain higher sustainable metabolic rates or PAL values during endurance events through strenuous training, consumption of large quantities of food, and capacity to process nutrients (Westerterp, 2001). While many studies show that differences in REE in very active individuals disappear when accounting for fat-free mass, the metabolic response to exercise varies. Thus, it is likely that these individuals will have higher TEEs. For example, the training regimen for many athletes undergoing heavy training consists of frequent periods of high-intensity exertion. A systematic review of 82 studies of 1,674 endurance athletes engaged in various sports showed TEE (measured by DLW or heart rate monitoring or accelerometry) was higher during the competition period than the preparation for competition period and an energy deficit was observed in both periods with TEE higher than energy intake (Heydenreich et al., 2017). Because energy intake also varied by the time period of training, recommendations to meet energy requirements would need to be adapted according to training or seasonal phases.

FINDINGS AND CONCLUSIONS

BMI and Health Outcomes

Findings

The committee finds that systematic reviews show that high BMI (in the WHO categories of overweight and obese) is associated with significantly increased risk for gestational diabetes, juvenile onset type 1 diabetes, childhood/adolescent asthma, prediabetes, type 2 diabetes, hypertension, stroke, premature myocardial infarct, coronary heart disease, several types of cancer, nonalcoholic fatty liver disease, age-related disability, and all-cause mortality, but lower risk of hip fracture.

Conclusions

The committee concludes that the body of evidence based on systematic reviews, meta-analysis, and mendelian randomization indicate a profound relationship between high BMI and functional disabilities, impaired quality of life, serious chronic disease states, and mortality. Limitations in the evidence reviewed by the committee support the need to understand the relationship between metabolically active tissues and organs, as well as the role of *ectopic fat in lean tissues and organs, on energy expenditure. This information is critical given the widespread prevalence of sarcopenic obesity in the general population and the growing awareness that obesity with sarcopenia may affect energy expenditure differently than obesity without sarcopenia.*

Weight Cycling and Health Outcomes

Findings

The committee finds that the evidence suggests that while mechanisms are unclear in terms of how weight cycling affects biological and physiological adaptations to body weight and affects health outcomes, concerns persist for long-term deleterious cardiometabolic health consequences. This is particularly true for outcomes known to be associated with obesity, such as type 2 diabetes, certain cancers, and both all-cause and CVD mortality.

Conclusions

The committee concludes that, considered collectively, the systematic reviews on weight cycling and health outcomes examined by the committee suggest that weight cycling appears to reduce REE in persons with obesity at baseline, especially in those who have severe obesity and those who cycle more frequently. However, these data are limited by small sample sizes, lack of standardized definition, and lack of more rigorous study designs such as DLW or metabolic chamber studies.

The committee concludes that the results of the systematic reviews on weight cycling and health outcomes support a need for consensus on a standard definition to improve interpretation, draw conclusions, and make applications from future research. There is a further need to include measures of food intake, diet type, diet pattern, and appetite in future research in order to discern the overall effect of weight cycling on energy balance.

Weight Change and Chronic Disease

Findings

The committee finds that systematic reviews of longitudinal studies examining the association between weight gain and chronic disease as well as mortality provided limited evidence of significance for a casual effect of weight change on disease risk and mortality. The systematic review that examined weight change measured from childhood to adulthood showed highly significant results for CVD incidence, hypertension, and type 2 diabetes when normal weight children became obese in adulthood and when obesity occurred in both childhood and adulthood.

Conclusions

The committee concludes that length of follow-up, removal of preexisting conditions, and if weight is measured are critical issues to reconcile in this body of literature. Given the increasing prevalence of chronic disease and other diet-related risk factors across the U.S. and Canadian populations, evidence is needed on medications that affect energy metabolism. In addition, research is needed on how energy metabolism, especially TEE, are affected by medications and procedures such as bariatric surgery.

REFERENCES

Alharbi, T. A., S. Paudel, D. Gasevic, J. Ryan, R. Freak-Poli, and A. J. Owen. 2021. The association of weight change and all-cause mortality in older adults: A systematic review and meta-analysis. *Age and Ageing* 50(3):697-704.

Apovian, C. M., J. Okemah, and P. M. O'Neil. 2019. Body weight considerations in the management of type 2 diabetes. *Advances in Therapy* 36(1):44-58.

Azizpour, Y., A. Delpisheh, Z. Montazeri, K. Sayehmiri, and B. Darabi. 2018. Effect of childhood BMI on asthma: A systematic review and meta-analysis of case-control studies. *BMC Pediatrics* 18(1):143.

Bosy-Westphal, A., B. Schautz, M. Lagerpusch, M. Pourhassan, W. Braun, K. Goele, M. Heller, C. C. Glüer, and M. J. Müller. 2013. Effect of weight loss and regain on adipose tissue distribution, composition of lean mass and resting energy expenditure in young overweight and obese adults. *International Journal of Obesity (2005)* 37(10):1371-1377.

Boullata, J., J. Williams, F. Cottrell, L. Hudson, and C. Compher. 2007. Accurate determination of energy needs in hospitalized patients. *Journal of the American Dietetic Association* 107(3):393-401.

Bourgi, K., C. A. Jenkins, P. F. Rebeiro, F. Palella, R. D. Moore, K. N. Altoff, J. Gill, C. S. Rabkin, S. J. Gange, M. A. Horberg, J. Margolick, J. Li, C. Wong, A. Willig, V. D. Lima, H. Crane, J. Thorne, M. Silverberg, G. Kirk, W. C. Mathews, T. R. Sterling, J. Lake, J. R. Koethe, and North American AIDS Cohort Collaboration on Research and Design. 2020. Weight gain among treatment-naive persons with HIV starting integrase inhibitors compared to non-nucleoside reverse transcriptase inhibitors or protease inhibitors in a large observational cohort in the United States and Canada. *Journal of the International AIDS Society* 23(4):e25484.

Byun, D., S. Hong, S. Ryu, Y. Nam, H. Jang, Y. Cho, N. Keum, and H. Oh. 2022. Early-life body mass index and risks of breast, endometrial, and ovarian cancers: A dose-response meta-analysis of prospective studies. *British Journal of Cancer* 126(4):664-672.

Chan, D. S. M., L. Abar, M. Cariolou, N. Nanu, D. C. Greenwood, E. V. Bandera, A. McTiernan, and T. Norat. 2019. World Cancer Research Fund International: Continuous update project-systematic literature review and meta-analysis of observational cohort studies on physical activity, sedentary behavior, adiposity, and weight change and breast cancer risk. *Cancer Causes and Control* 30(11):1183-1200.

Church, T. S., M. J. LaMonte, C. E. Barlow, and S. N. Blair. 2005. Cardiorespiratory fitness and body mass index as predictors of cardiovascular disease mortality among men with diabetes. *Archives of Internal Medicine* 165(18):2114-2120.

Darbandi, M., Y. Pasdar, S. Moradi, H. J. J. Mohamed, B. Hamzeh, and Y. Salimi. 2020. Discriminatory capacity of anthropometric indices for cardiovascular disease in adults: A systematic review and meta-analysis. *Preventing Chronic Disease* 17:E131.

Dickerson, R. N., and L. Roth-Yousey. 2005. Medication effects on metabolic rate: A systematic review (part 1). *Journal of the American Dietetic Association* 105(5):835-843.

Dugani, S. B., Y. M. Hydoub, A. P. Ayala, R. Reka, T. Nayfeh, J. F. Ding, S. N. McCafferty, M. Alzuabi, M. Farwati, M. H. Murad, A. A. Alsheikh-Ali, and S. Mora. 2021. Risk factors for premature myocardial infarction: A systematic review and meta-analysis of 77 studies. *Mayo Clinic Proceedings: Innovations, Quality and Outcomes* 5(4):783-794.

EFSA (European Commission, the Panel on Dietetic Products, Nutrition, and Allergies). 2013. Scientific opinion on Dietary Reference Values for energy. *EFSA Journal* 11(1):3005.

El Ghoch, M., S. Calugi, and R. Dalle Grave. 2018. Weight cycling in adults with severe obesity: A longitudinal study. *Nutrition & Dietetics* 75(3):256-262.

Evans, W. J., J. E. Morley, J. Argiles, C. Bales, V. Baracos, D. Guttridge, A. Jatoi, K. Kalantar-Zadeh, H. Lochs, G. Mantovani, D. Marks, W. E. Mitch, M. Muscaritoli, A. Najand, P. Ponikowski, F. Rossi Fanelli, M. Schambelan, A. Schols, M. Schuster, D. Thomas, R. Wolfe, and S. D. Anker. 2008. Cachexia: A new definition. *Clinical Nutrition* 27(6):793-799.

Fothergill, E., J. Guo, L. Howard, J. C. Kerns, N. D. Knuth, R. Brychta, K. Y. Chen, M. C. Skarulis, M. Walter, P. J. Walter, and K. D. Hall. 2016. Persistent metabolic adaptation 6 years after "The Biggest Loser" competition. *Obesity (Silver Spring)* 24(8):1612-1619.

Gao, J., X. Lin, Y. He, Y. Fu, Y. Wu, J. Liao, Y. Wu, and X. Lian. 2019. The comparison of different obesity indexes and the risk of lung cancer: A meta-analysis of prospective cohort studies. *Nutrition and Cancer* 71(6):908-921.

Gonzalez, M. C., M. Correia, and S. B. Heymsfield. 2017. A requiem for BMI in the clinical setting. *Current Opinion in Clinical Nutrition and Metabolic Care* 20(5):314-321.

Gu, D., M. Tang, Y. Wang, H. Cui, M. Zhang, Y. Bai, Z. Zeng, Y. Tan, X. Wang, and B. Zhang. 2022. The causal relationships between extrinsic exposures and risk of prostate cancer: A phenome-wide Mendelian randomization study. *Frontiers in Oncology* 12.

Hao, Y., M. Jiang, Y. Miao, X. Li, C. Hou, X. Zhang, H. Chen, X. Zhong, and J. Li. 2021. Effect of long-term weight gain on the risk of breast cancer across women's whole adulthood as well as hormone-changed menopause stages: A systematic review and dose-response meta-analysis. *Obesity Research & Clinical Practice* 15(5):439-448.

He, W., Q. Li, M. Yang, J. Jiao, X. Ma, Y. Zhou, A. Song, S. B. Heymsfield, S. Zhang, and S. Zhu. 2015. Lower BMI cutoffs to define overweight and obesity in China. *Obesity (Silver Spring)* 23(3):684-691.

Heydenreich, J., B. Kayser, Y. Schutz, and K. Melzer. 2017. Total energy expenditure, energy intake, and body composition in endurance athletes across the training season: A systematic review. *Sports Medicine Open* 3(1):8.

Hidayat, K., H. J. Li, and B. M. Shi. 2018. Anthropometric factors and non-Hodgkin's lymphoma risk: Systematic review and meta-analysis of prospective studies. *Critical Reviews in Oncology-Hematology* 129:113-123.

Hidayat, K., S. Y. Zou, and B. M. Shi. 2019. The influence of maternal body mass index, maternal diabetes mellitus, and maternal smoking during pregnancy on the risk of childhood-onset type 1 diabetes mellitus in the offspring: Systematic review and meta-analysis of observational studies. *Obesity Reviews* 20(8):1106-1120.

Ibe, A., and T. C. Smith. 2014. Diabetes in US women on the rise independent of increasing BMI and other risk factors; a trend investigation of serial cross-sections. *BMC Public Health* 14:954.

Javed, A. A., J. Ma, L. N. Anderson, A. J. Mayhew, H. Y. So, L. E. Griffith, A. Gilsing, and P. Raina. 2022. Age-appropriate BMI cut-points for cardiometabolic health risk: A cross-sectional analysis of the Canadian longitudinal study on aging. *International Journal of Obesity (2005)* 46(5):1027-1035.

Jayedi, A., A. Rashidy-Pour, M. Khorshidi, and S. Shab-Bidar. 2018. Body mass index, abdominal adiposity, weight gain and risk of developing hypertension: A systematic review and dose-response meta-analysis of more than 2.3 million participants. *Obesity Reviews* 19(5):654-667.

Jayedi, A., A. Rashidy-Pour, S. Soltani, M. S. Zargar, A. Emadi, and S. Shab-Bidar. 2020. Adult weight gain and the risk of cardiovascular disease: A systematic review and dose-response meta-analysis of prospective cohort studies. *European Journal of Clinical Nutrition* 74(9):1263-1275.

Jiang, M., Y. Zou, Q. Xin, Y. Cai, Y. Wang, X. Qin, and D. Ma. 2019. Dose-response relationship between body mass index and risks of all-cause mortality and disability among the elderly: A systematic review and meta-analysis. *Clinical Nutrition* 38(4):1511-1523.

Karahalios, A., D. R. English, and J. A. Simpson. 2017. Change in body size and mortality: A systematic review and meta-analysis. *International Journal of Epidemiology* 46(2):526-546.

Khadra, D., L. Itani, H. Tannir, D. Kreidieh, D. El Masri, and M. El Ghoch. 2019. Association between sarcopenic obesity and higher risk of type 2 diabetes in adults: A systematic review and meta-analysis. *World Journal of Diabetes* 10(5):311-323.

Kim, K. S., W. L. Owen, D. Williams, and L. L. Adams-Campbell. 2000. A comparison between BMI and conicity index on predicting coronary heart disease: The Framingham Heart Study. *Annals of Epidemiology* 10(7):424-431.

Kim, M. S., W. J. Kim, A. V. Khera, J. Y. Kim, D. K. Yon, S. W. Lee, J. I. Shin, and H. H. Won. 2021. Association between adiposity and cardiovascular outcomes: An umbrella review and meta-analysis of observational and Mendelian randomization studies. *European Heart Journal* 42(34):3388-3403.

Kitahara, C. M., A. J. Flint, A. Berrington de Gonzalez, L. Bernstein, M. Brotzman, R. J. MacInnis, S. C. Moore, K. Robien, P. S. Rosenberg, P. N. Singh, E. Weiderpass, H. O. Adami, H. Anton-Culver, R. Ballard-Barbash, J. E. Buring, D. M. Freedman, G. E. Fraser, L. E. Beane Freeman, S. M. Gapstur, J. M. Gaziano, G. G. Giles, N. Håkansson, J. A. Hoppin, F. B. Hu, K. Koenig, M. S. Linet, Y. Park, A. V. Patel, M. P. Purdue, C. Schairer, H. D. Sesso, K. Visvanathan, E. White, A. Wolk, A. Zeleniuch-Jacquotte, and P. Hartge. 2014. Association between class III obesity (BMI of 40-59 kg/m2) and mortality: A pooled analysis of 20 prospective studies. *PLoS Medicine* 11(7):e1001673.

Larsson, S. C., and S. Burgess. 2021. Causal role of high body mass index in multiple chronic diseases: A systematic review and meta-analysis of Mendelian randomization studies. *BMC Medicine* 19(1):320.

Lauby-Secretan, B., C. Scoccianti, D. Loomis, Y. Grosse, F. Bianchini, K. Straif, and International Agency for Research on Cancer Handbook Working Group. 2016. Body fatness and cancer--viewpoint of the IARC working group. *New England Journal of Medicine* 375(8):794-798.

LeBlanc, E. S., C. D. Patnode, E. M. Webber, N. Redmond, M. Rushkin, and E. A. O'Connor. 2018. Behavioral and pharmacotherapy weight loss interventions to prevent obesity-related morbidity and mortality in adults updated evidence report and systematic review for the US Preventive Services Task Force. *JAMA* 320(11):1172-1191.

Li, H., D. Boakye, X. Chen, M. Hoffmeister, and H. Brenner. 2021. Association of body mass index with risk of early-onset colorectal cancer: Systematic review and meta-analysis. *American Journal of Gastroenterology* 116(11):2173-2183.

Li, K., W. Shi, F. Zhao, C. Yang, Q. Dai, B. Wang, and Y. Li. 2019. Changes in energy expenditure of patients with obesity following bariatric surgery: A systematic review of prospective studies and meta-analysis. *Obesity Surgery* 29(7):2318-2337.

Li, Z. M., Z. X. Wu, B. Han, Y. Q. Mao, H. L. Chen, S. F. Han, J. L. Xia, and L. S. Wang. 2016. The association between BMI and gallbladder cancer risk: A meta-analysis. *Oncotarget* 7(28):43669-43679.

Liu, X., Q. Sun, H. Hou, K. Zhu, Q. Wang, H. Liu, Q. Zhang, L. Ji, and D. Li. 2018a. The association between BMI and kidney cancer risk: An updated dose-response meta-analysis in accordance with PRISMA guideline. *Medicine (United States)* 97(44).

Liu, X., D. Zhang, Y. Liu, X. Sun, Y. Hou, B. Wang, Y. Ren, Y. Zhao, C. Han, C. Cheng, F. Liu, Y. Shi, X. Chen, L. Liu, G. Chen, S. Hong, M. Zhang, and D. Hu. 2018b. A J-shaped relation of BMI and stroke: Systematic review and dose-response meta-analysis of 4.43 million participants. *Nutrition, Metabolism and Cardiovascular Diseases* 28(11):1092-1099.

Ma, C., A. Avenell, M. Bolland, J. Hudson, F. Stewart, C. Robertson, P. Sharma, C. Fraser, and G. MacLennan. 2017. Effects of weight loss interventions for adults who are obese on mortality, cardiovascular disease, and cancer: Systematic review and meta-analysis. *BMJ* 359:j4849.

McClave, S. A., B. E. Taylor, R. G. Martindale, M. M. Warren, D. R. Johnson, C. Braunschweig, M. S. McCarthy, E. Davanos, T. W. Rice, G. A. Cresci, J. M. Gervasio, G. S. Sacks, P. R. Roberts, C. Compher, Society of Critical Care Medicine, and American Society for Parenteral and Enteral Nutrition. 2016. Guidelines for the provision and assessment of nutrition support therapy in the adult critically ill patient: Society of critical care medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.). *JPEN Journal of Parenteral and Enteral Nutrition* 40(2):159-211.

Meigs, J. B., P. W. Wilson, C. S. Fox, R. S. Vasan, D. M. Nathan, L. M. Sullivan, and R. B. D'Agostino. 2006. Body mass index, metabolic syndrome, and risk of type 2 diabetes or cardiovascular disease. *Journal of Clinical Endocrinology and Metabolism* 91(8):2906-2912.

Mortensen, S. J., I. Beeram, J. Florance, K. Momenzadeh, A. Mohamadi, E. K. Rodriguez, A. von Keudell, and A. Nazarian. 2021. Modifiable lifestyle factors associated with fragility hip fracture: A systematic review and meta-analysis. *Journal of Bone and Mineral Metabolism* 39(5):893-902.

Oshima, T., C. P. Heidegger, and C. Pichard. 2016. Supplemental parenteral nutrition is the key to prevent energy deficits in critically ill patients. *Nutrition in Clinical Practice* 31(4):432-437.

O'Sullivan, D. E., R. L. Sutherland, S. Town, K. Chow, J. Fan, N. Forbes, S. J. Heitman, R. J. Hilsden, and D. R. Brenner. 2021. Risk factors for early-onset colorectal cancer: A systematic review and meta-analysis. *Clinical Gastroenterology and Hepatology* 20(6):1229-1240, e1225.

Pasco, J. A., G. C. Nicholson, S. L. Brennan, and M. A. Kotowicz. 2012. Prevalence of obesity and the relationship between the body mass index and body fat: Cross-sectional, population-based data. *PloS One* 7(1):e29580.

Powell-Wiley, T. M., P. Poirier, L. E. Burke, J. P. Despres, P. Gordon-Larsen, C. J. Lavie, S. A. Lear, C. E. Ndumele, I. J. Neeland, P. Sanders, M. P. St-Onge, American Heart Association Council on Lifestyle and Cardiometabolic Health, Council on Cardiovascular and Stroke Nursing, Council on Clinical Cardiology, Council on Epidemiology and Prevention, and Stroke Council. 2021. Obesity and cardiovascular disease: A scientific statement from the American Heart Association. *Circulation* 143(21):e984-e1010.

Ramuth, H., S. Hunma, V. Ramessur, M. Ramuth, C. Monnard, J. P. Montani, Y. Schutz, N. Joonas, and A. G. Dulloo. 2020. Body composition-derived BMI cut-offs for overweight and obesity in ethnic Indian and Creole urban children of Mauritius. *British Journal of Nutrition* 124(5):481-492.

Rexrode, K. M., J. E. Buring, and J. E. Manson. 2001. Abdominal and total adiposity and risk of coronary heart disease in men. *International Journal of Obesity and Related Metabolic Disorders* 25(7):1047-1056.

Rhee, E. J. 2017. Weight cycling and its cardiometabolic impact. *Journal of Obesity and Metabolic Syndrome* 26(4):237-242.

SACN (Scientific Advisory Committee on Nutrition). 2011. *Dietary Reference Values for energy*. London, UK: The Stationery Office Limited.

Sharma, V., S. Coleman, J. Nixon, L. Sharples, J. Hamilton-Shield, H. Rutter, and M. Bryant. 2019. A systematic review and meta-analysis estimating the population prevalence of comorbidities in children and adolescents aged 5 to 18 years. *Obesity Reviews* 20(10):1341-1349.

Sohn, W., H. W. Lee, S. Lee, J. H. Lim, M. W. Lee, C. H. Park, and S. K. Yoon. 2021. Obesity and the risk of primary liver cancer: A systematic review and meta-analysis. *Clinical and Molecular Hepatology* 27(1):157-174.

Sun, J., B. Xi, L. Yang, M. Zhao, M. Juonala, and C. G. Magnussen. 2021. Weight change from childhood to adulthood and cardiovascular risk factors and outcomes in adulthood: A systematic review of the literature. *Obesity Reviews* 22(3).

Van Soom, T., S. El Bakkali, N. Gebruers, H. Verbelen, W. Tjalma, and E. van Breda. 2020. The effects of chemotherapy on energy metabolic aspects in cancer patients: A systematic review. *Clinical Nutrition* 39(6):1863-1877.

WCRF/AICR (World Cancer Research Fund/American Institute for Cancer Research). 2018. *Body fatness and weight gain and the risk of cancer.* https://www.wcrf.org/wp-content/uploads/2021/01/Body-fatness-and-weight-gain_0.pdf (accessed November 25, 2022).

Weir, C. B., and A. Jan. 2022. BMI classification percentile and cut off points. In *Statpearls*. Treasure Island (FL). https://www.ncbi.nlm.nih.gov/books/NBK541070/ (accessed December 8, 2022).

Westerterp, K. R. 2001. Limits to sustainable human metabolic rate. *Journal of Experimental Biology* 204(Pt 18):3183-3187.

WHO (World Health Organization). 2016a. *Global database on body mass index*. https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/body-mass-index (accessed November 25, 2022).

WHO. 2016b. *Global report on diabetes.* https://www.who.int/publications/i/item/9789241565257 (accessed November 25, 2022).

WHO. 2021. *Obesity and overweight*. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed November 25, 2022).

WHO. 2022. *WHO European regional obesity report 2022*. Copenhagen, Denmark: World Health Organization, Regional Office for Europe.

Youssef, M. R., A. S. C. Reisner, A. S. Attia, M. H. Hussein, M. Omar, A. LaRussa, C. A. Galvani, M. Aboueisha, M. Abdelgawad, E. A. Toraih, G. W. Randolph, and E. Kandil. 2021. Obesity and the prevention of thyroid cancer: Impact of body mass index and weight change on developing thyroid cancer - pooled results of 24 million cohorts. *Oral Oncology* 112:105085.

Yu, H. J., M. Ho, X. Liu, J. Yang, P. H. Chau, and D. Y. T. Fong. 2022. Association of weight status and the risks of diabetes in adults: A systematic review and meta-analysis of prospective cohort studies. *International Journal of Obesity (2005)* 46(6):1101-1113.

Zembura, M., and P. Matusik. 2022. Sarcopenic obesity in children and adolescents: A systematic review. *Frontiers in Endocrinology* 13:914740.

Zhang, X., J. Rhoades, B. J. Caan, D. E. Cohn, R. Salani, S. Noria, A. A. Suarez, E. D. Paskett, and A. S. Felix. 2019. Intentional weight loss, weight cycling, and endometrial cancer risk: A systematic review and meta-analysis. *International Journal of Gynecological Cancer* 29(9):1361-1371.

Zhang, Y., C. M. Xiao, Y. Zhang, Q. Chen, X. Q. Zhang, X. F. Li, R. Y. Shao, and Y. M. Gao. 2021. Factors associated with gestational diabetes mellitus: A meta-analysis. *Journal of Diabetes Research* 2021:6692695.

Zhou, W., Y. Shi, Y. Q. Li, Z. Ping, C. Wang, X. Liu, J. Lu, Z. X. Mao, J. Zhao, L. Yin, D. Zhang, Z. Tian, L. Zhang, and L. Li. 2018. Body mass index, abdominal fatness, and hypertension incidence: A dose-response meta-analysis of prospective studies. *Journal of Human Hypertension* 32(5):321-333.

Zou, H., P. Yin, L. Liu, W. Liu, Z. Zhang, Y. Yang, W. Li, Q. Zong, and X. Yu. 2019. Body-weight fluctuation was associated with increased risk for cardiovascular disease, all-cause and cardiovascular mortality: A systematic review and meta-analysis. *Frontiers in Endocrinology* 10:728.

Zou, H., P. Yin, L. Liu, W. Duan, P. Li, Y. Yang, W. Li, Q. Zong, and X. Yu. 2021. Association between weight cycling and risk of developing diabetes in adults: A systematic review and meta-analysis. *Journal of Diabetes Investigation* 12(4):625-632.

9

Research Recommendations

The committee identified areas where additional research would be useful as it assessed data obtained from its umbrella reviews. This chapter presents those research gaps and recommendations to fill them, which span four topic areas: factors affecting energy requirements, energy metabolism in special population groups, weight change and energy metabolism, and application of the Estimated Energy Requirement (EER) to individuals and population groups.

FACTORS AFFECTING ENERGY REQUIREMENTS

Limited data and systematic review evidence are available on how factors such as macronutrient composition of the diet, the gut microbiome, dietary fiber, and genetic factors affect energy requirements at all life stages. Such information would be particularly valuable for individuals participating in doubly labeled water (DLW) studies.

To better determine the EER for pregnant women, more DLW data and body composition data on pregnant women is needed across all prepregnancy body mass index (BMI) categories. These data could be analyzed to identify energy needs of pregnant women who have gained within the Institute of Medicine 2009 gestational weight gain recommendations and pregnant women who have gained outside of those recommendations.

Research Recommendation 1

The committee recommends that the National Institutes of Health (NIH), the U.S. Department of Agriculture (USDA), the Centers for Disease Control and Prevention (CDC), the Department of Veterans Affairs (VA), and Health Canada commit funding to nutrition and kinesiology research that would inform future updates of the Dietary Reference Intakes (DRIs) for energy in all sex and life-stage groups. The committee further recommends research on methodologies to individualize energy requirements when providing precision nutrition care.

ENERGY METABOLISM IN SPECIAL POPULATION GROUPS

Energy metabolism data on diverse racial/ethnic groups, including indigenous populations in the United States and Canada, is scarce. Along with a research focus on more diverse population groups a critical research need is the inclusion of ancestry data in order to stratify study participants. Also lacking is evidence on factors that affect energy metabolism and energy requirements in transgender populations.

The effect of sarcopenic obesity on energy requirements in individuals of all age, sex, and BMI groups is not well understood, nor is energy balance, energy expenditure, and energy compensation in individuals with BMI $\geq$ 50. Additionally, data from DLW studies is lacking for infants, children, adolescents, the oldest old, and lactating women.

Given the increasing prevalence of chronic disease and other diet-related risk factors across the U.S. and Canadian populations, evidence is needed on medications that affect energy metabolism. In addition, research is needed on how medications and procedures such as bariatric surgery affect energy metabolism, especially total energy expenditure (TEE).

Research Recommendation 2

The committee recommends that NIH, USDA, CDC, VA, and Health Canada commit funding to nutrition research that would inform future updates of the DRIs in diverse populations, including infants, children, and adolescents, the oldest old, lactating women, and individuals taking medications and those at higher body mass index (BMI) levels.

WEIGHT CHANGE AND ENERGY METABOLISM

There is insufficient evidence on defining a weight cycle and determining what frequency, amount, and duration of cycling indicates a significant effect on energy metabolism. In addition, reporting on how weight change is measured is inconsistent and information on population characteristics and research methodologies relating to the measurement of body weight are inadequately reported in many research articles.

Research Recommendation 3

The committee recommends that investigators studying energy balance and national health surveillance monitoring provide participants' rationales for weight gain or weight loss. In addition, published research reports should indicate whether weight change was measured or self-reported. Nutrition and kinesiology researchers should also use accepted definitions that differentiate basal and resting metabolic rate to standardize terminology in reporting study findings.

Research Recommendation 4

The committee further recommends that research agencies develop a checklist of quality factors (to guide study designs and protocols and to evaluate study quality) that are relevant to evaluating energy intake imbalances and to relating intake imbalances to health outcomes. Journal editors should require documentation from authors to show that articles accepted for publication have met quality factors for assessing energy intake imbalances.

APPLICATION OF THE EER TO INDIVIDUALS AND POPULATION GROUPS

To support translation to population-level survey data and application for recommendations, research is needed on the relationship between total energy expenditure and physical activity levels (PALs) with metrics that define physical activity intensity and duration. This could be facilitated by including devices to measure steps and physical activity in DLW studies as well as self-reported physical activity behavior. There is a paucity of DLW-derived PALs with metrics in the pediatric population (infants, children, and adolescents).

Because of the complexity in factors associated with the selection of the PAL and calculating the EERs, there is a potential for error in the calculation of the EER owing to misclassification.

Research Recommendation 5

The committee recommends that USDA, the U.S. Food and Drug Administration, NIH, and Health Canada commit funding to develop an app to facilitate calculations of EERs for specific life-stage groups to ensure the wide *dissemination and appropriate application of the new EERs. Additionally, CDC and Canada's Health Statistics agencies should incorporate into their national health surveys measures of physical activity that are compatible with the physical activity level (PAL) categories needed to calculate EERs. Those U.S. and Canadian agencies that fund research to support public health initiatives should invest in development and validation of measures of physical activity that can be used in public health and research contexts.*

Appendix A

Acronyms and Abbreviations

AI	Adequate Intake
AMDR	Acceptable Macronutrient Distribution Range
AMSTAR	Assessment of Multiple Systematic Reviews
BEE	basal energy expenditure
BM	breast milk
BMI	body mass index
BMR	basal metabolic rate
BRFSS	Behavioral Risk Factor Surveillance System
CCHS	Canadian Community Health Survey
CDC	Centers for Disease Control and Prevention
CDRR	Chronic Disease Risk Reduction Intake
CHMS	Canadian Health Measures Survey
CVD	cardiovascular disease
DIT	diet-induced thermogenesis
DLW	doubly labeled water
DRI	Dietary Reference Intake
DXA	dual-energy X-ray absorptiometry
EAR	Estimated Average Intake
EER	Estimated Energy Requirement

FFM	fat-free mass
FFQ	food frequency questionnaire
FM	fat mass
g	gram
GRADE	Grading of Recommendations Assessment, Development, and Evaluation
GWG	gestational weight gain
IAEA	International Atomic Energy Agency
Kcal	kilocalorie
kJ	kilojoule
m	meter
MeSH	medical subject heading
MI	myocardial infarction
MVPA	moderate to vigorous physical activity
NAFLD	nonalcoholic fatty liver disease
NEAT	nonexercise activity thermogenesis
NHANES	National Health and Nutrition Examination Survey
NIH	National Institutes of Health
NPNL	non-pregnant non-lactating
PAEE	physical activity energy expenditure
PAL	physical activity level
PIECOD	population, intervention [exposure], comparators, outcomes, study designs
RDA	Recommended Dietary Allowance
REE	resting energy expenditure
RMR	resting metabolic rate
SD	standard deviation
SE	standard error
SR	systematic review
T2DM	type 2 diabetes mellitus
TEE	total energy expenditure
TEF	thermic effect of food

UL	Tolerable Upper Intake Level
WC	waist circumference
WHO	World Health Organization

Appendix B

Committee Member Biographies

Anna Maria Siega-Riz, Ph.D. (*chair*), was appointed dean of the School of Public Health and Health Sciences at the University of Massachusetts Amherst in May 2019. Her research focuses on the first 1,000 days of life by understanding the influence of maternal weight status and dietary patterns and behaviors in the etiology of various pregnancy and child health outcomes. Her current funded research explores the concept of food reward and sensitivity among pregnant women and early determinants of childhood obesity and the association of maternal preconceptional health with childhood eating and weight status among Hispanics. Other research interests include examining the determinants and consequences of food insecurity and the implications of food policy on health outcomes. Dr. Siega-Riz currently serves on the National Institutes of Health's Council of Councils; the National Academies of Sciences, Engineering, and Medicine's Health and Medicine Division Advisory Committee; and the Food and Nutrition Board and is a board of trustees member for the International Food Information Council. She holds a B.S.P.H. from the University of North Carolina, Gillings School of Global Public Health, an M.S. in food, nutrition, and food service management from the University of North Carolina at Greensboro, and a Ph.D. in nutrition with a minor in epidemiology from the University of North Carolina, Gillings School of Global Public Health. She held the credentials of a registered dietitian from 1983 to 2014.

Regan L. Bailey, Ph.D., M.S., R.D., is associate director of precision nutrition for the Institute for Advancing Health Through Agriculture and professor of nutrition at Texas A&M University. She previously served as a professor in the Department of Nutrition Science at Purdue University and directed the Indiana Clinical and Translational Science Institute, Purdue Diet Assessment Center. Prior to Purdue, Dr. Bailey was a Nutritional Epidemiologist and Director of Career Development and Outreach at the NIH Office of Dietary Supplements. The focus of research in the Bailey lab is to improve the methods of measuring nutritional status to optimize health. She uses nationally representative survey data to characterize the American dietary landscape, to identify the optimal methods for assessment of biomarkers of nutritional status, and importantly, to understand how dietary intakes relate to health outcomes. Her work has identified differences in nutritional exposures by sex, race, ethnicity, life stage, and income, suggesting the need for population-specific interventions and public health policy. She is the author of more than 150 peer-reviewed scientific publications and has been elected to the National Academy of Medicine for her research contributions. Dr. Bailey is a Registered Dietitian, who completed a dietetic internship and M.S. in food and nutrition from the Indiana University of Pennsylvania. Dr. Bailey received her Ph.D. in nutrition science from the Pennsylvania State University and completed an M.P.H. from the Bloomberg School of Public Health at Johns Hopkins University. Dr. Bailey was a member of the 2021 National Academies' Committee on Scanning for New Evidence on Riboflavin to Support a Dietary Reference Intake Review.

Ethan M. Balk, M.D., M.P.H., is professor of health services, policy, and practice in the Center for Evidence Synthesis in Health and is Codirector of the Brown Evidence-based Practice Center, both within the Brown University School of Public Health. Previously, he was based in the Center for Evidence-based Medicine at Tufts Medical Center. Dr. Balk is an internist with over 20 years of experience conducting and leading more than 100 systematic reviews. He has led numerous systematic reviews and related reports for AHRQ, several NIH institutes and offices, FDA, the CDC-sponsored Community Task Force, and the World Health Organization, among others. He has also led numerous reviews on nutrition-related topics, including those to support prior NASEM DRI reports. Dr. Balk received his M.D. from Tufts University School of Medicine and his M.P.H. in epidemiology and biostatistics from Tufts University. Dr. Balk led the systematic review team to support the NASEM Committee on Evidence-Based Practices for Public Health Emergency Preparedness and Response in 2019 and 2020.

Susan I. Barr, Ph.D., is professor emeritus at the University of British Columbia, Vancouver, Canada, where she enjoyed a long and varied research and teaching career. Her research interests included exploring associations among women's eating attitudes and cognitions, the menstrual cycle, and bone health. She also conducted survey research, including dietary intake assessment. Dr. Barr is a member of the Canadian Nutrition Society and the American Society for Nutrition. She has received awards for research, teaching, and service, including the Ryley-Jeffs Award (Dietitians of Canada), the Earle Willard Henry Award (Canadian Nutrition Society), and a Killam Teaching Award from the University of BC. Dr. Barr received her undergraduate degree in nutrition from UBC and completed her Ph.D. in nutrition at the University of Minnesota prior to beginning her career at UBC. She was a member and chair of the National Academies' Subcommittee on Interpretation and Uses of Dietary Reference Intakes (1998–2003), a member of the Standing Committee on Dietary Reference Intakes (2003–2005), and a member of the Committee for the Development of Guiding Principles for the Inclusion of Chronic Disease Endpoints in Future Dietary Reference Intakes (2016–2017).

Loneke T. Blackman Carr, Ph.D. (until May 9, 2022), is an assistant professor of community and public health nutrition at the University of Connecticut in the Department of Nutritional Sciences. Her research expertise centers on behavioral weight control interventions to treat obesity. Within this research context, her scholarly agenda centers on health disparities in obesity, nutrition, and physical activity that affect Black adults, especially women. Dr. Blackman Carr is a member of the Academy of Nutrition and Dietetics and the Society of Behavioral Medicine (SBM). Within SBM, she serves on the Membership Committee and participates in their inaugural Diversity Institute. Her education and training include an M.A. in nutrition science and dietetics from Syracuse University and a Ph.D. in nutrition intervention and policy from the University of North Carolina at Chapel Hill. She received dietetic training from Cornell University and completed postdoctoral training at Duke University at the Samuel DuBois Cook Center on Social Equity.

Nancy F. Butte, Ph.D., M.P.H., was recognized as Distinguished Emeritus Professor upon her retirement from Baylor College of Medicine after a 36-year career at the USDA/ARS Children's Nutrition Research Center within the Department of Pediatrics. Dr. Butte's primary area of research is energy metabolism, with an emphasis on infant and child energy requirements and maternal energy requirements during pregnancy and lactation. Through these studies, her expertise developed in the fields of calorimetry, physical activity, childhood obesity, and genetics of obesity. In 2017, Dr. Butte was made Fellow of the American Society of Nutrition. She also was a member of the Society of Pediatric Research, the Obesity Society, and the American Dietetic Association. Dr. Butte received her M.P.H. in public health nutrition and her Ph.D. in nutritional sciences from the University of California, Berkeley. Dr. Butte served on the 1999–2001 Institute of Medicine Committee on Dietary Reference Intakes of Energy and Macronutrients. She also was a member of the 2001–2004 FAO/WHO/UNU Expert Consultation on Energy and Protein in Human Nutrition. She previously consulted with Nestlé on a publication in *Current Developments in Nutrition* on energy requirements in infants and young children. Also, relevant to setting the DRIs for pregnant women, Dr. Butte was a member of the 1988–1989 National Academy of Sciences Subcommittee on Nutritional Status and Weight Gain during Pregnancy and the 2008–2009 Institute of Medicine Committee on Reexamination of IOM Pregnancy Weight Guidelines.

Scott E. Crouter, Ph.D., is currently an associate professor in the Department of Kinesiology, Recreation, and Sport Studies and director of the Applied Physiology Laboratory at the University of Tennessee Knoxville. He was previously an assistant/associate professor at the University of Massachusetts Boston (2007–2013) and was a postdoctoral associate at Cornell University in the Division of Nutritional Sciences (2005–2007). Dr. Crouter's main research interest is in the area of measuring physical activity and energy expenditure in adults and youth using wearable physical activity monitors. Related to this work, he has received several NIH awards and has served on committees within the National Physical Activity Plan Alliance (U.S. Report Card for Children and Adolescents Advisory Committee) and Centers for Disease Control and Prevention and National Collaborative on Childhood Obesity Research (development of a youth compendium of physical activities). Dr. Crouter is a Fellow of the American College of Sports Medicine. Dr. Crouter's primary training has been in exercise physiology. He received his Ph.D. from the University of Tennessee Knoxville (2005), M.S. from the University of Wisconsin—La Crosse (2000), and B.S. from Linfield College (1998).

Amy H. Luke, Ph.D., is professor and chair of the Department of Public Health Sciences at the Parkinson School of Health Sciences and Public Health, Loyola University Chicago. She began at Loyola in the spring of 1994 as a postdoctoral fellow focused on the association of energy metabolism and chronic diseases. For the past 28 years, Dr. Luke has used objective measures, including doubly labeled water and accelerometry, to understand the effect of energy expenditure on obesity, hypertension, chronic kidney disease, and diabetes in multiple African-origin populations across the epidemiologic transition; current research is being conducted in South Africa, Ghana, Seychelles, Jamaica, and the United States. She is currently a member of the management group for the IAEA DLW Database and serves on the IAEA consultancy for the Preparation of E4.30.37. Total Energy Expenditure Across the Life Course in Low- and Middle-Income Countries. She is also a member of the Obesity Society and the American Public Health Association. Dr. Luke received her Ph.D. in human nutrition and nutritional biology at the University of Chicago where she was trained in stable isotopes and their application in nutrition research, including doubly labeled water.

Susan B. Roberts, Ph.D. (until June 16, 2022), is team leader in the Energy Metabolism Laboratory, Jean Mayer USDA Human Nutrition Research Center on Aging; Professor of Nutrition at Tufts University and Codirector of the Tufts Institute for Global Obesity Research; and Adjunct Professor of Psychiatry and Scientific Staff Member in Pediatrics, Tufts Medical School. Dr. Roberts is internationally recognized for her work on weight regulation, including energy requirements across the life span, dietary composition and weight regulation, and biobehavioral determinants of energy intake. She also develops novel behavioral interventions for weight management. In addition to her U.S. work, she coleads an international consortium of scientists dedicated to addressing obesity worldwide. Dr. Roberts has published more than 250 research papers and has an H-index of 63. She has been the awardee of preeminent awards for national and international nutrition research, including the 2009 E.V. McCollum Award of the American Society for Nutrition and the 2016 W. O. Atwater Lecturer. Dr. Roberts completed her Ph.D. in nutrition at the University of Cambridge in the U.K. and her postdoctoral training at the Massachusetts Institute of Technology. Dr. Roberts was a member of the 2002 National Academies' Committee on Dietary Reference Intakes for Energy and Macronutrients and was a member of the 2016 Committee to Review the Process to Update the Dietary Guidelines for Americans.

Heidi J. Silver, Ph.D., is a research professor at Vanderbilt University Medical Center and a health scientist in the Veterans Affairs Department of Research. Dr. Silver's research focuses on designing diet intervention trials that modify energy intake and the amounts and types of macronutrients consumed to improve energy balance, body composition, inflammatory state, and insulin sensitivity for cardiometabolic disease risk reduction. She established and directs the Vanderbilt Diet, Body Composition, and Human Metabolism Core. In 2020, she was selected for the Academy of Nutrition and Dietetics Excellence in Research Practice Award. She has published more than 50 peer-reviewed articles, taught several academic courses, and created several webinars. Dr. Silver is an ad hoc reviewer for 21 journals, has been invited to speak at more than 75 national meetings, and has been invited to present lectures or workshops in 9 different countries. Dr. Silver achieved her Ph.D. in nutrition in 2001 from Florida International University, where she was honored with Doctoral Recognition of the Year and Outstanding Doctoral Scholarship Awards.

Janet A. Tooze, Ph.D., is a professor in the Department of Biostatistics and Data Science, Division of Public Health Sciences, at the Wake Forest School of Medicine. She is a biostatistician with expertise in statistical methods in nutrition, focused on dietary assessment and measurement error. She has developed methods for estimating the usual intake of foods and nutrients in a unified framework, termed the NCI Method, the foundation of which is a statistical model developed by Dr. Tooze for repeated measures data with excess zeroes. This method is used internationally to characterize population intakes of foods and nutrients and for risk assessment. She led the statistical validation of the Healthy Eating Index 2015, a widely used diet quality index. She has received three National Institutes of Health Merit Awards in recognition of her work in the advancement of dietary assessment. Dr. Tooze received an M.P.H. in public health from the Harvard School of Public Health and a Ph.D. in biometrics from the University of Colorado. She was a member of the 2017–2019 National Academies' Committee to Review the Dietary Reference Intakes for Sodium and Potassium.

William W. Wong, Ph.D., is Distinguished Emeritus Professor of Pediatrics at Baylor College of Medicine and past director of the Gas-Isotope-Ratio Mass Spectrometry Laboratory and chairman of the Center-wide Equipment Maintenance/Repair Program at the USDA/ARS Children's Nutrition Research Center. Other than performing the first whole-room indirect calorimetric validation of the doubly labeled water (DLW) method, he was involved in many studies defining the energy requirements in infants, toddlers, adolescents, pregnant and lactating women, and women with twin pregnancy as well as adolescents with heart failure and cancer. In addition to his expertise in the stable isotope methods, he was the project director of a multisite, randomized, placebo-controlled clinical study to document the efficacy and safety of soy isoflavones to prevent osteoporosis in menopausal women, as well as the project director of Healthy Kids Houston, a community-based program to promote healthy lifestyles among minority children with support from the City of Houston Parks and Recreation Department, the Houston Metropolitan Transit Authority, YMCA, and the Houston Independent School District. He also led a team of pediatricians, dietitians, nutritionists, and a psychotherapist to develop the summer camp program, Kamp K'aana, to promote healthy lifestyles among obese children. The program is now an official program at the YMCA in Houston and Wisconsin. He was one of the original key scientists to help establish the International Atomic Energy Agency DLW Database. Dr. Wong will serve on the Data and Safety Monitoring Board for the Nutritional Interventions Planning Projects of the National Institute of Aging. He received his B.S. degree in chemistry and his M.S. and Ph.D. degrees in oceanography. In spite of his lack of official training in nutrition, biochemistry, and human physiology, he was able to develop research projects with diverse research interests and worked effectively in a multidisciplinary setting.

Elizabeth A. Yetley, Ph.D., retired from the Office of Dietary Supplements (ODS) at the National Institutes of Health (NIH) in 2008, after having served as Senior Nutrition Research Scientist for 4 years. Subsequently, she was contracted by ODS for the next 9 years to work on specific projects that were of interest to the organization. From 1980 to 2004, she worked as a nutrition scientist at the U.S. Food and Drug Administration (FDA), eventually attaining the rank of Lead Nutrition Scientist. Dr. Yetley provided leadership for several projects at both NIH and FDA that included health claims for nutrition labels, folic acid fortification, methodological challenges for assessing folate and vitamin D biomarkers of status, and systematic reviews for Dietary Reference Intakes, as well as other nutrition topics such as vitamin D and omega-3 fatty acids. She also provided regulatory leadership for infant formulas, medical foods, and dietary supplements. She received numerous awards from various organizations, including the FDA, NIH, Health and Human Services' Secretary, American Society for Nutrition, University of Massachusetts, and Iowa State University. She received her B.S., M.S., and Ph.D. in nutrition from Iowa State University. Dr. Yetley was a member of the 2017–2019 National Academies' Committee to Review the Dietary Reference Intakes for Sodium and Potassium.

Appendix C

Open-Session Agendas

FEBRUARY 4, 2022

Session 1

10:00 a.m.	Introductions and Chair's Statement *Anna Maria Siega-Riz, Committee Chair*
10:10	Use of Doubly Labeled Water to Support Analysis of Energy Requirements John Speakman, Institute of Biological and Environmental Sciences, University of Aberdeen, Scotland
10:30	Q&A *Amy Luke, Committee Member*
10:50	Physical Activity and Long-Term Body Weight Regulation John Jakicic, Translational Research Institute at AdventHealth Orlando
11:10	NHANES and Physical Activity Richard Troiano, Epidemiology and Genomics Research Program, National Cancer Institute

11:30	Q&A *Susan Roberts, Committee Member*
12:00 pm	Break

Session 2

1:00 p.m.	Introductions *Anna Maria Siega-Riz, Committee Chair*
1:05	Impact of Dietary Macronutrient Content on Energy Metabolism Kevin Hall, Integrative Physiology Section, National Institute of Diabetes and Digestive and Kidney Diseases
1:45	Q&A *Heidi Silver, Committee Member*
2:15	Closing Remarks *Anna Maria Siega-Riz, Committee Chair*
2:30 pm	Adjourn

MARCH 31, 2022

12:30 p.m.	Energy Values for Human Milk *Kellie Casavale, U.S. Food and Drug Administration* *Kathryn Hopperton, Health Canada*
12:50	Q&A
1:00	Energy Requirements to Support Pregnancy Weight Gain and Lactation at Varying BMIs Leanne Redman, Pennington Biomedical Research Center
1:20	Q&A
1:30	Adjourn Open Session

Appendix D

Literature Search Strategies and Results

Key Question: What is the association between body mass index (BMI) and chronic disease, including all-cause mortality?
Date: March 24, 2022

Search Parameters:
Date: 2017–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	*body mass/ or *obesity/ or *underweight/ or *body weight/ or (body-mass or BMI or body-mass-index or body-ban-mass or quetelet-index or z-score or zscore or obesity or adipose-tissue-hyperplasia or adipositas or adiposity or alimentary-obesity or body-weight-excess or excess-body-weight or corpulency or fat-overload-syndrome or nutritional-obesity or obesitas or overweight or thinness or weight-insufficiency or normal-weight or body-weight or weight-body or weight-status).ti,ab.	1,127,797

Search No.	Syntax	Results
2	*cardiovascular disease/ or *congenital heart disease/ or *non insulin dependent diabetes mellitus/ or *malignant neoplasm/ or hypertension/ or *hip fracture/ or *all cause mortality/ or *maternal mortality/ or *preeclampsia/ or *infant mortality/ or *premature labor/ or (cardiovascular-disease* or angiocardiopathy or angiocardiovascular-disease* or cardiovascular-complication* or cardiovascular-disturbance* or cardiovascular-lesion* or cardiovascular-syndrome* or cardiovascular-vegetative-disorder* or complication-cardiovascular* or disease-cardiovascular or major-adverse-cardiovascular-event* or congenital-heart-disease* or congenital-cardiac-disease* or congenital-cardiac-distress* or congenital-heart-distress* or congenital-heart-failure* or heart-congenital-disease* or neonatal-cardiopathy or truncus-arteriosus-persistent* or adult-onset-diabetes or diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-type-2 or diabetes-type-II or diabetes-adult-onset or dm-2 or insulin-independent-diabetes or ketosis-resistant-diabetes-mellitus or maturity-onset-diabetes or NIDDM or non-insulin-dependent-diabetes or non-insulin-dependent-diabetes-mellitus or noninsulin-dependent-diabetes or T2DM or type2-diabetes or type-II-diabetes or cancer* or malignant-neoplasia or malignant-neoplasm* or malignant-neoplastic-disease* or malignant-tumor* or malignant-tumour* or neoplasia-malignant or tumor-malignant or tumour-malignant or hypertension or blood-pressure-high or high-blood-pressure or high-renin-hypertension or hypertensive-disease* or hypertensive-effect* or hypertensive-effect* or hypertensive-response or hip-fracture* or broken-hip* or fracture-hip* or fractured-hip* or all-cause-mortality or maternal-mortality or mortality-maternal or mother-mortality or preeclampsia or pre-eclampsia or pre-eclamptic-toxaemia or pre-eclamptic-toxemia or preclampsia or preeclamptic-taxaemia or preeclamptic-toxemia or toxaemia-preeclamptic or toxemia-preeclamptic or infant-mortality or infantile-mortality or mortality-infant* or premature-labor or labor-premature or labour-premature or obstetric-labor-premature or obstetric-labour-premature or premature-delivery or premature-labour or premature-obstetric-labor or premature-obstetric-labour or preterm-birth or preterm-delivery or preterm-labor or preterm-labour or physical-growth).ti,ab.	4,302,981

Search No.	Syntax	Results
3	risk factor/ or (risk-factor* or relative-risk*).ti,ab. or risk-of.ti.	1,972,996
4	1 and 2 and 3	117,461
5	limit 4 to (english language and yr="2017 -Current")	29,784
6	limit 5 to "systematic review"	1,374

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(body-mass or BMI or body-mass-index or body-ban-mass or quetelet-index or z-score or zscore or obesity or adipose-tissue-hyperplasia or adipositas or adiposity or alimentary-obesity or body-weight-excess or excess-body-weight or corpulency or fat-overload-syndrome or nutritional-obesity or obesitas or overweight or thinness or weight-insufficiency or normal-weight or body-weight or weight-body or weight-status).ti,ab,kw.	310
2	(cardiovascular-disease* or angiocardiopathy or angiocardiovascular-disease* or cardiovascular-complication* or cardiovascular-disturbance* or cardiovascular-lesion* or cardiovascular-syndrome* or cardiovascular-vegetative-disorder* or complication-cardiovascular* or disease-cardiovascular or major-adverse-cardiovascular-event* or congenital-heart-disease* or congenital-cardiac-disease* or congenital-cardiac-distress* or congenital-heart-distress* or congenital-heart-failure* or heart-congenital-disease* or neonatal-cardiopathy or truncus-arteriosus-persistent* or adult-onset-diabetes or diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-type-2 or diabetes-type-II or diabetes-adult-onset or dm-2 or insulin-independent-diabetes or ketosis-resistant-diabetes-mellitus or maturity-onset-diabetes or NIDDM or non-insulin-dependent-diabetes or non-insulin-dependent-diabetes-mellitus or noninsulin-dependent-diabetes or T2DM or type2-diabetes or type-II-diabetes or cancer* or malignant-neoplasia or malignant-neoplasm* or malignant-neoplastic-disease* or malignant-tumor* or malignant-tumour* or neoplasia-malignant or tumor-malignant or tumour-malignant or hip-fracture* or broken-hip* or fracture-hip* or fractured-hip* or all-cause-mortality or maternal-mortality or mortality-maternal or mother-mortality or preeclampsia or pre-eclampsia or pre-eclamptic-toxaemia or pre-eclamptic-toxemia or preclampsia	2,258

Search No.	Syntax	Results
	or preeclamptic-taxaemia or preeclamptic-toxemia or toxaemia-preeclamptic or toxemia-preeclamptic or infant-mortality or infantile-mortality or mortality-infant* or premature-labor or labor-premature or labour-premature or obstetric-labor-premature or obstetric-labour-premature or premature-delivery or premature-labour or premature-obstetric-labor or premature-obstetric-labour or preterm-birth or preterm-delivery or preterm-labor or preterm-labour or physical-growth).ti,ab,kw.	
3	risk*.ti,ab,kw.	6,674
4	1 and 2 and 3	88
5	limit 4 to last 5 years	40

Medline (Ovid):

Search No.	Syntax	Results
1	Body Mass Index/ or Overweight/ or Obesity/ or Thinness/ or (body-mass-index or bmi or index-body-mass or index-quetelet or quetelet-index or quetelets-index or zscore or z-score or overweight or obesity or leanness or thinness or underweight).ti,ab.	525,591
2	Cardiovascular Diseases/ or Heart Defects, Congenital/ or Diabetes Mellitus, Type 2/ or Neoplasms/ or Hypertension/ or Hip Fractures/ or Maternal Mortality/ or Pre-Eclampsia/ or Infant Mortality/ or Premature Birth/ or (cardiovascular-disease* or disease-cardiovascular or abnormality-heart or congenital-heart-defect* or congenital-heart-disease* or defect-congenital-heart or defects-congenital-heart or disease-congenital-heart or heart-abnormalit* or heart-defect-congenital or heart-defects-congenital or heart-disease-congenital or heart-malformation-of or malformation-of-heart* or adult-onset-diabetes-mellitus or diabetes-maturity-onset or diabetes-mellitus-adult-onset or diabetes-mellitus-ketosis-resistant or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-mellitus-noninsulin-dependent or diabetes-mellitus-slow-onset or diabetes-mellitus-stable or diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-type-2 or ketosis-resistant-diabetes-mellitus or mody or maturity-onset-diabetes or maturity-onset-diabetes-mellitus or niddm or non-insulin-dependent-diabetes-mellitus or slow-onset-diabetes-mellitus or stable-diabetes-mellitus	4,814,116

Search No.	Syntax	Results
	or type-2-diabetes or neoplasm* or cancer* or malignancies or malignancy or neoplasia* or tumor* or hypertension or blood-pressure-high or blood-pressures-high or high-blood-pressure* or fractures-hip or fractures-intertrochanteric or fractures-subtrochanteric or fractures-trochanteric or hip-fractures or intertrochanteric-fracture* or trochanteric-fracture* or all-cause-mortality or maternal-mortality or maternal-mortalities or mortalities-maternal or mortality-maternal or preeclampsia-eclampsia or eph-complex or eph-gestosis or eph-toxemia* or eclampsia-1-preeclampsia or eclampsia-1s-preeclampsia or edema-proteinuria-hypertension-gestosis or gestosis-eph or gestosis-edema-proteinuria-hypertension or gestosis-hypertension-edema-proteinuria or gestosis-proteinuria-edema-hypertension or hypertension-edema-proteinuria gestosis or pre-eclampsia or preeclampsia or pregnancy-toxemia* or proteinuria-edema-hypertension-gestosis or toxemia-eph or toxemia-of-pregnanc* or toxemia-pregnancy or toxemias-pregnancy or toxemias-eph or infant-mortalit* or mortalities-infant or mortality-infant or mortalities-neonatal or mortalities-postneonatal or mortality-infant* or mortality-neonatal or mortality-postneonatal or neonatal-mortalit* or postneonatal-mortalit* or premature-birth* or birth-premature or birth-preterm or births-premature or births-preterm or preterm-birth* or growth*).ti,ab.	
3	Risk Factors/ or (risk-factor* or factor-risk or health-correlate* or population-at-risk or populations-at-risk or risk-of).ti,ab.	2,427,333
4	1 and 2 and 3	105,024
5	limit 4 to (english language and yr="2017 -Current" and "systematic review")	1,149

Key Question: What is the effect of BMI (and other measures of adiposity) on energy balance or energy expenditure?
Date: March 15, 2022

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	Exp energy metabolism/ or exp energy expenditure/ or exp energy balance/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab.	215,665
2	body mass/ or waist hip ratio/ or waist circumference/ or weight height ratio/ or body fat percentage/ or (body-mass or BMI or body-mass-index or body-ban-mass or quetelet-index or waist-hip-ratio or hip-to-waist-ratio or hip-waist-ratio or waist-to-hip-ratio or waist-circumference or waist-size or weight-height-ratio or height-to-weight-ratio or height-weight-ratio or weight-to-height-ratio or body-fat-percentage or %BF or body-fat-percent or bodyfat-percentage or percent-body-fat or percentage-of-body-fat or percentage-of-bodyfat).ti,ab.	716,486
3	1 and 2	18,256
4	limit 3 to (english language and "systematic review" and yr="2000 -Current")	259

Medline (Ovid):

Search No.	Syntax	Results
1	exp Energy Metabolism/ or (bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure*).ti,ab.	438,295
2	Body Mass Index/ or Waist Hip Ratio/ or Waist Circumference/ or (body-mass-index or index-body-mass or index-quetelet or quetelets-index or waist-hip-ratio or hip-to-waist-ratio or hip-waist-ratio or waist-to-hip-ratio or waist-circumference or circumference-waist or weight-height-ratio or height-to-weight-ratio or height-weight-ratio or weight-to-height-ratio or body-fat-percentage or %BF or body-fat-percent or bodyfat-percentage or percent-body-fat or percentage-of-body-fat or percentage-of-bodyfat). ti,ab.	267,883
3	1 and 2	8,125
4	limit 3 to (english language and yr="2000 -Current" and "systematic review")	63

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab,kw.	9
2	(body-mass or BMI or body-mass-index or body-ban-mass or quetelet-index or waist-hip-ratio or hip-to-waist-ratio or hip-waist-ratio or waist-to-hip-ratio or waist-circumference or waist-size or weight-height-ratio or height-to-weight-ratio or height-weight-ratio or weight-to-height-ratio or body-fat-percentage or %BF or body-fat-percent or bodyfat-percentage or percent-body-fat or percentage-of-body-fat or percentage-of-bodyfat).ti,ab,kw.	117
3	1 and 2	3

Key Question: What is the association of body composition on metabolic efficiency (energy usage/expenditure)?
Date: February 23, 2022

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Databases: Embase (Ovid) 1974 to 2022 February 22; Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid)

Search No.	Syntax	Results
1	*energy metabolism/ or *energy expenditure/ or *energy balance/	30,030
2	*body composition/ or *body fat distribution/ or *body weight/ or *body mass/ or *skinfold thickness/ or *waist hip ratio/ or *obesity/ or *body weight change/ or *underweight/	272,239
3	1 and 2	3,103
4	limit 3 to (human and english language and yr="2000 -Current")	1,406
5	systematic review.mp. or "systematic review"/	434,492
6	4 and 5	25

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	energy.ti,ab,kw.	124
2	(body-composition or composition-body or body-fat-distribution or body-weight or total-body-weight or weight-body or body-mass or body-mass-index or body-ban-mass or quetelet-index or skinfold-thickness or skin-fold-thickness or skin-fold-measurement* or skin-thickness or skinfold-measurement* or waist-hip-ratio or hip-to-waist-ratio or hip-waist-ratio or waist-to-hip-ratio or adipose-tissue-hyperplasia or adipositas or adiposity or alimentary-obesity or body-weight-excess or corpulency or fat-overload-syndrome or nutritional-obesity or obesitas or overweight or body-weight-change* or weight-change* or underweight or thinness or weight-insufficiency).ti,ab,kw.	261
3	1 and 2	35

Key Question: Identify DLW studies that may not be included in the IAEA database
Date: January 31, 2022

Search Parameters:
Date: 2000–Present
Document Type: All
Language: English
Database: Medline (Ovid)

Search:
Ovid MEDLINE® and Epub Ahead of Print, In-Process, In-Data-Review and Other Nonindexed Citations, Daily and Versions <1946 to January 31, 2022>

Search No.	Syntax	Results
1	"doubly labelled water".mp.	484
2	"doubly labeled water".mp.	1,069
3	1 or 2	1,542
4	limit 3 to (english language and humans and yr="2000 -Current")	885

Key Question: How does the increase in tissue deposition associated with growth during infancy, childhood, adolescence, pregnancy, and lactation influence, effect, or contribute to energy requirements?
Date: June 8, 2022

Search Parameters:
Date: 1980–Present
Document Type: All
Language: English
Databases: Medline (Ovid); Embase (Ovid)

Ovid MEDLINE®
Energy Cost of Pregnancy

Search No.	Syntax	Results
1	exp Growth/ or exp Gestational Weight Gain/ or exp Weight Gain/ or exp Body Composition/ or exp Anthropometry/ or exp "Body Weights and Measures"/ or (growth or gain-weight or gains-weight or weight-gain* or body-composition* or composition-body or compositions-body or doubly-labeled-water-method or doubly-labelled-water-	2,243,329

Search No.	Syntax	Results
	technique or anthropometry or body-measure* or body-weights-and-measures or measures-body or measure-body or gestational-weight-gain or maternal-weight-gain or postpartum-weight-retention or pregnancy-weight-gain or weight-gain-gestational or weight-gain-maternal or weight-gain-pregnancy or weight-retention-postpartum).ti,ab.	
2	exp Pregnancy/ or exp Pregnant Women/ or (pregnancy or gestation or pregnancies or pregnant-woman or pregnant-women or woman-pregnant or women-pregnant).ti,ab.	1,050,557
3	exp Energy Metabolism/ or exp Basal Metabolism/ or (energy-metabolism or bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or basal-metabolic-rate* or basal-metabolism or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic-rate or resting-metabolic-rates or energy-cost* or energy-consumption or energy-transfer* or energy-requirement* or energy-balance*).ti,ab.	481,614
4	1 and 2 and 3	2,805
5	Longitudinal studies/	158,248
6	4 and 5	53
7	limit 6 to (english language and humans and yr="1980 -Current")	48

Ovid MEDLINE®
Energy Cost of Lactation

Search No.	Syntax	Results
1	exp Energy Metabolism/ or exp Basal Metabolism/ or (energy-metabolism or bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or basal-metabolic-rate* or basal-metabolism or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic-rate or resting-metabolic-rates or energy-cost* or energy-consumption or energy-transfer* or energy-requirement* or energy-balance*).ti,ab.	481,614
2	exp Lactation/ or exp Milk, Human/ or (lactation or lactation-prolonged or lactations-prolonged or milk-secretion* or prolonged-lactation* or breastmilk or breast-milk or human-milk or milk-breast or milk-human).ti,ab.	83,615

Search No.	Syntax	Results
3	Longitudinal studies/	158,248
4	1 and 2	3,635
5	3 and 4	43
6	limit 5 to (english language and humans and yr="1980 -Current")	38

Ovid MEDLINE®
Energy Cost of Growth

Search No.	Syntax	Results
1	exp Energy Metabolism/ or exp Basal Metabolism/ or (energy-metabolism or bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or basal-metabolic-rate* or basal-metabolism or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic-rate or resting-metabolic-rates or energy-cost* or energy-consumption or energy-transfer* or energy-requirement* or energy-balance*).ti,ab.	481,614
2	exp Growth/ or exp Child Development/ or exp Weight Gain/ or exp Body Composition/ or exp Anthropometry/ or exp "Body Weights and Measures"/ or (growth or child-development or development-child or development-infant or infant-development or gain-weight or gains-weight or weight-gain* or body-composition* or composition-body or compositions-body or doubly-labeled-water-method or doubly-labelled-water-technique or anthropometry or body-measure* or body-weights-and-measures or measures-body or measure-body).ti,ab.	2,300,924
3	exp Adolescent/ or exp Child/ or exp Infant/ or (adolescence or adolescent* or teen* or teenager* or youth* or child* or infant*).ti,ab.	4,135,479
4	1 and 2 and 3	6,676
5	Longitudinal studies/	158,248
6	4 and 5	266
7	limit 6 to (english language and humans and yr="1980 -Current")	254

Embase (Ovid)
Energy Cost of Lactation

Search No.	Syntax	Results
1	exp "energy cost"/ or exp energy metabolism/ or exp basal metabolic rate/ or (energy-cost* or energy-expenditure* or caloric-expenditure* or energy-metabolism* or metabolism-energy or energy-consumption or energy-transfer* or energy-requirement* or energy-balance or basal-metabolism or basal-metabolism-rate or basal-oxygen-consumption or basic-metabolic-rate or basic-metabolism or bmr or energy-content or energy-composition).ti,ab.	296,447
2	exp lactation/ or exp breast milk/ or (lactation or breast-secretion or lactic-secretion or mammary-gland-secretion* or milk-excretion or milk-release* or milk-secretion* or breast-milk or breastmilk or breast-fed-infant* or homogenized-pasteurized-human-milk or human-milk or maternal-milk or milk-human or milk-mother or mother-milk or woman-milk).ti,ab.	101,836
3	Longitudinal study/	173,158
4	1 and 2	4,033
5	3 and 4	35
6	limit 5 to (human and english language and yr="1980 -Current")	26

Embase (Ovid)
Energy Cost of Pregnancy

Search No.	Syntax	Results
1	exp "energy cost"/ or exp energy metabolism/ or exp basal metabolic rate/ or (energy-cost* or energy-expenditure* or caloric-expenditure* or energy-metabolism* or metabolism-energy or energy-consumption or energy-transfer* or energy-requirement* or energy-balance or basal-metabolism or basal-metabolism-rate or basal-oxygen-consumption or basic-metabolic-rate or basic-metabolism or bmr or energy-content or energy-composition).ti,ab.	296,447
2	exp body growth/ or exp gestational weight gain/ or exp body weight gain/ or exp body composition/ or exp growth rate/ or exp doubly labeled water technique/ or exp anthropometry/ or (body-growth or growth-body or somatic-growth or growth or body-weight-gain or body-weight-increase or weight-gain or weight-increase or body-composition	2,145,031

Search No.	Syntax	Results
	or composition-body or growth-rate* or growth-rate-relative or growth-velocity or rate-growth or relative-growth-rate or velocity-growth or doubly-labeled-water-method or doubly-labelled-water-technique or anthropometry or anthropometric-index or anthropometrics or antropometry or body-measurement* or tissue-deposition*or gestational-weight-gain or pregnancy-weight-gain).ti,ab.	
3	exp pregnancy/ or exp pregnant woman/ or (pregnancy or child-bearing or childbearing or gestation or gravidity or intrauterine-pregnancy or labor-presentation or labour-presentation or pregnancy-maintenance or pregnancy-trimester* or pregnant-woman or pregnant-women).ti,ab.	1,003,515
4	1 and 2 and 3	1,823
5	longitudinal study/	173,158
6	4 and 5	31
7	limit 6 to (human and english language and yr="1980 -Current")	28

Embase (Ovid)
Energy Cost of Growth

Search No.	Syntax	Results
1	exp "energy cost"/ or exp energy metabolism/ or exp basal metabolic rate/ or (energy-cost* or energy-expenditure* or caloric-expenditure* or energy-metabolism* or metabolism-energy or energy-consumption or energy-transfer* or energy-requirement* or energy-balance or basal-metabolism or basal-metabolism-rate or basal-oxygen-consumption or basic-metabolic-rate or basic-metabolism or bmr or energy-content or energy-composition).ti,ab.	296447
2	exp body growth/ or exp postnatal growth/ or exp body weight gain/ or exp body composition/ or exp growth rate/ or exp doubly labeled water technique/ or exp anthropometry/ or (body-growth or growth-body or somatic-growth or postnatal-growth or child-growth or infant-growth or growth or body-weight-gain or body-weight-increase or weight-gain or weight-increase or body-composition or composition-body or growth-rate* or growth-rate-relative or growth-velocity or rate-growth or relative-growth-rate or velocity-growth or doubly-labeled-water-method or doubly-labelled-water-	2148604

Search No.	Syntax	Results
	technique or anthropometry or anthropometric-index or anthropometrics of anthropometry or body-measurement* or tissue-deposition*).ti,ab.	
3	exp adolescent/ or exp child/ or (adolescent* or teenager* or child* or infant*).ti,ab.	4299109
4	1 and 2 and 3	5744
5	longitudinal study/	173158
6	4 and 5	165
7	limit 6 to (human and english language and yr="1980 -Current")	155

Key Question: What equations are available for computing or calculating basal energy expenditure (BEE), basal metabolic rate (BMR), and resting metabolic rate (RMR)?
Date: April 20, 2022

Search Parameters:
Date: 2012–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	exp energy metabolism/ or exp energy expenditure/ or exp energy balance/ or exp basal metabolic rate/ or exp resting metabolic rate/ or exp resting energy expenditure/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy or basal-metabolism or basal-oxygen-consumption or basic-metabolic-rate* or basic-metabolism or BMR or BEE or resting-metabolic-rate or RMR or resting-energy-expenditure).ti,ab.	264,392
2	equation*.ti,ab,kw.	232,344
3	1 and 2	5,780
4	limit 3 to (english language and "systematic review" and yr="2012 -Current")	34

Medline (Ovid):

Search No.	Syntax	Results
1	exp Energy Metabolism/ or exp basal metabolic rate/ or (bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure* or Basal-metabolism or basal-metabolic-rate* or basal-metabolism or metabolic-rate-basal or metabolic-rate-resting or metabolism-basal or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic-rate* or BMR or RMR or BEE or basal-energy-expenditure* or resting-energy-expenditure*).ti,ab.	453,951
2	equation*.ti,ab,kw.	139,671
3	1 and 2	4,750
4	limit 3 to (english language and yr="2012 -Current" and "systematic review")	16

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure* or Basal-metabolism or basal-metabolic-rate* or basal-metabolism or metabolic-rate-basal or metabolic-rate-resting or metabolism-basal or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic-rate* or BMR or RMR or BEE or basal-energy-expenditure* or resting-energy-expenditure*).ti,ab,kw.	11
2	equation*.ti,ab,kw.	17
3	1 and 2	0

Key Question: What is the effect of race or ethnicity on energy expenditure?
Date: April 19, 2022 (Search 1)

Search Parameters:
Date: 2012–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	**Syntax**	**Results**
1	exp energy metabolism/ or exp energy expenditure/ or exp energy balance/ or exp basal metabolic rate/ or exp resting metabolic rate/ or exp resting energy expenditure/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy or basal-metabolism or basal-oxygen-consumption or basic-metabolic-rate* or basic-metabolism or BMR or resting-metabolic-rate or RMR or resting-energy-expenditure).ti,ab.	249,873
2	exp "ethnic or racial aspects"/ or exp ancestry group/ or (ethnic-aspect* or racial-aspect* or cultural-factor* or ethnic-difference* or ethnicity or race* or racial-factor* or racial-difference* or ancestry-group or continental-population-group* or racial-group*).ti,ab.	712,617
3	1 and 2	3,066
4	limit 3 to (english language and "systematic review" and yr="2012 -Current")	31

Medline (Ovid):

Search No.	Syntax	Results
1	exp Energy Metabolism/ or exp Basal Metabolism/ or (bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure* or Basal-metabolism or basal-metabolic-rate* or basal-metabolism or metabolic-rate-basal or metabolic-rate-resting or metabolism-basal or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic or resting-metabolic-rate* or BMR or RMR or basal-energy-expenditure* or resting-energy-expenditure* or REE).ti,ab.	443,449
2	exp Population Groups/ or (population-group* or group-population or groups-population).ti,ab.	323,768
3	1 and 2	1,490
4	limit 3 to (english language and yr="2012 -Current" and "systematic review")	8

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure* or Basal-metabolism or basal-metabolic-rate* or basal-metabolism or metabolic-rate-basal or metabolic-rate-resting or metabolism-basal or rate-basal-metabolic or rate-resting-metabolic or resting-metabolic or resting-metabolic-rate* or BMR or RMR or basal-energy-expenditure* or resting-energy-expenditure* or REE).ti,ab,kw.	9
2	(population-group* or group-population or groups-population or race or ethnicity).ti,ab,kw.	81
3	1 and 2	0

Date: June 2, 2022 (Search 2)

Search Parameters:
Date: 1980–Present
Document Type: All
Language: English
Database: PubMed

PubMed

Search No.	Syntax	Results
1	African Americans [MeSH Terms]	60,282
2	Blacks [MeSH Terms]	94,672
3	Whites [MeSH Terms]	70,830
4	(Hispanic [MeSH Terms]) OR (Latino [MeSH Terms])	36,377
5	(American Indians [MeSH Terms]) OR (Alaska Natives [MeSH Terms])	1,106
6	Asian Americans [MeSH Terms]	8,634
7	(Native Hawaiian [MeSH Terms]) OR (Pacific Islander [MeSH Terms])	1,1671
8	1 or 2 or 3 or 4 or 5 or 6 or 7	160,632
9	energy metabolism [MeSH Terms]	406,915
10	basal metabolism [MeSH Terms]	8,616
11	body composition [MeSH Terms]	61,583
12	9 or 10 or 11	461,143
13	8 AND 12	2,318
14	limit 13 to (English language and yr="1980 -Current" and Humans)	2,245

Date: June 8, 2022
Search results were further restricted using Endnote
Title must contain: energy metabolism or energy requirement(s) or basal metabolism or body composition or energy expenditure or energy balance or metabolic rate
Final results: 465 papers

Key Question: What is the association of macronutrient composition of the diet on metabolic efficiency (energy usage/expenditure)?
Date: February 23, 2022

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Databases: Embase (Ovid) 1974 to 2022 February 22; Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid)

Search No.	Syntax	Results
1	*energy metabolism/ or *energy expenditure/ or *energy balance/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab.	103,565
2	exp macronutrient/ or macronutrient*.ti,ab.	17,270
3	exp diet therapy/ or exp low carbohydrate diet/ or exp carbohydrate loading diet/ or exp ketogenic diet/ or exp low fat diet/ or exp protein diet/ or exp paleolithic diet/ or exp protein restriction/ or (metabolic-efficienc* or diet-therap* or diet-intervention* or diet-treatment* or dietary-intervention* or dietary-therap* or dietary-treatment* or nutrition-therap* or nutritional-therap* or carbohydrate-restricted-diet* or carbohydrate-poor-diet* or diet-low-carbohydrate* or low-carb-diet* or carbohydrate-loading or diet-carbohydrate-loading or diet-ketogenic* or keto-diet* or ketogenous-diet* or ketotic-diet* or diet-fat-restricted or diet-low-fat or fat-diet-low or fat-restricted-diet* or fat-restriction* or lipid-restricted-diet* or lipid-restriction or low-lipid-diet* or diet-high-protein or diet-protein or high-protein-diet* or protein-meal* or protein-enriched-diet* or protein-rich-diet* or caveman-diet* or diet-paleolithic or hunter-gatherer-diet* or paleo-diet* or stone-age-diet* or borst-diet* or diet-borst or diet-giovanetti or diet-protein-poor or diet-protein-restricted or giovanetti-diet* or hypoprotein-diet* or low-protein-diet* or protein-free-diet* or protein-poor-diet* or protein-restricted-diet*).ti,ab.	402,614
4	1 and 2 and 3	452
5	limit 4 to (human and english language and yr="2000 -Current")	354
6	"systematic review"/ or systematic review*.mp.	434,492
7	5 and 6	12

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	energy.ti,ab,kw.	124
2	macronutrient*.af.	111
3	(metabolic-efficienc* or diet-therap* or diet-intervention* or diet-treatment* or dietary-intervention* or dietary-therap* or dietary-treatment* or nutrition-therap* or nutritional-therap* or carbohydrate-restricted-diet* or carbohydrate-poor-diet* or diet-low-carbohydrate* or low-carb-diet* or carbohydrate-loading or diet-carbohydrate-loading or diet-ketogenic* or keto-diet* or ketogenous-diet* or ketotic-diet* or diet-fat-restricted or diet-low-fat or fat-diet-low or fat-restricted-diet* or fat-restriction* or lipid-restricted-diet* or lipid-restriction or low-lipid-diet* or diet-high-protein or diet-protein or high-protein-diet* or protein-meal* or protein-enriched-diet* or protein-rich-diet* or caveman-diet* or diet-paleolithic or hunter-gatherer-diet* or paleo-diet* or stone-age-diet* or borst-diet* or diet-borst or diet-giovanetti or diet-protein-poor or diet-protein-restricted or giovanetti-diet* or hypoprotein-diet* or low-protein-diet* or protein-free-diet* or protein-poor-diet* or protein-restricted-diet*).ti,ab,kw.	155
4	1 and 2 and 3	14

Key Question: What is the degree of systematic bias (random error, measurement error, or misreporting) of energy intake as assessed by self-report (diet records, 24-hour recalls, or food frequency questionnaires) compared to doubly labeled water studies?
Date: April 19, 2022

Search Parameters:
Date: 2012–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	exp caloric intake/ or (energy-intake* or caloric-intake* or calorie-intake* or calory-intake* or dietary-energy or intake-caloric).ti,ab.	81,476

Search No.	Syntax	Results
2	exp statistical bias/ or exp random error/ or exp error/ or (bias or statistical-bias* or systematic-bias* or truncation-bias* or random-error* or error* or error-stud* or human-error* or mistake* or misreport*).ti,ab.	997,855
3	exp self report/ or exp medical record/ or exp food frequency questionnaire/ or exp doubly labeled water technique/ or (self-report* or diet-record* or medical-record* or health-record* or patient-record* or 24-hour-recall* or food-frequency-questionnaire* or doubly-labeled-water-stud* or doubly-labeled-water-technique*).ti,ab.	679,482
4	1 and 2 and 3	594
5	limit 4 to (english language and "systematic review" and yr="2012 -Current")	23

Medline (Ovid):

Search No.	Syntax	Results
1	exp Energy Intake/ or (energy-intake* or caloric-intake* or calorie-intake*).ti,ab.	65,015
2	exp Bias/ or (bias* or outcome-measurement-error* or error-outcome-measurement* or random-error* or measurement-error* or misreport*).ti,ab.	274,133
3	exp Self Report/ or exp Diet Records/ or exp "Surveys and Questionnaires"/ or (report-self or self-report* or diet-record* or diaries-food or diary-food or diet-record* or dietary-record* or food-diar* or record-diet* or records-diet* or survey* or questionnaire* or doubly-labeled-water).ti,ab.	1,777,781
4	1 and 2 and 3	595
5	limit 4 to (english language and yr="2012 -Current" and "systematic review")	14

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(energy-intake* or caloric-intake* or calorie-intake* or calory-intake* or dietary-energy or intake-caloric). ti,ab,kw.	45
2	(bias* or statistical-bias* or systematic-bias* or truncation-bias* or random-error* or error* or error-stud* or human-error* or mistake* or misreport*). ti,ab,kw.	5,023

Search No.	Syntax	Results
3	(self-report* or diet-record* or medical-record* or health-record* or patient-record* or 24-hour-recall* or food-frequency-questionnaire* or doubly-labeled-water-stud* or doubly-labeled-water-technique*). ti,ab,kw.	218
4	1 and 2 and 3	1

Key Questions:
How do physical activity and energy expenditure change across the life span?
What is the relationship between different measurements of physical activity and energy expenditure?
Date: March 15, 2022

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	exp energy metabolism/ or exp energy expenditure/ or exp energy balance/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab.	247,779
2	physical activity/ or exercise/ or sedentary lifestyle/ or (physical-activity or activity-physical or exercise or biometric-exercise or effort or exercise-capacity or exercise-performance or exercise-training or exertion or fitness-training or fitness-workout or physical-conditioning-human or physical-effort or physical-exercise or physical-exertion or physical-work-out or physical-workout or free-living-activit* or sedentary-behavior* or sedentary-behaviour* or sedentary-lifestyle* or sedentary-life-style or volume-of-activit* or physical-activity-intensit* or MetS or metabolic-syndrome* or kcal* or total-activity-count*).ti,ab.	977,819
3	1 and 2	36,471
4	limit 3 to (english language and yr="2000 -Current")	29,334

Search No.	Syntax	Results
5	Limit 4 to "systematic review"	514
6	accelerometer/ or self report/ or indirect calorimeter/ or oxygen consumption/ or (wearable-physical-activity-monitor* or accelerometer* or meter-accelero or objective-measure* or subjective-measure* or self-report* or diary or physical-activity-questionnaire* or indirect-calorimeter* or indirect-calorimetry or portable-calorimeter* or room-calorimeter* or oxygen-consumption* or consumption-oxygen or consumptions-oxygen or VO2 or doubly-labeled-water).ti,ab.	482,260
7	3 and 6	11,598
8	Limit 7 to (english language and yr="2000-Current" and "systematic review"	135

Medline (Ovid):

Search No.	Syntax	Results
1	exp Energy Metabolism/ or (bioenergetic* or energy-expenditure* or energy-metabolism* or expenditure-energy or expenditures-energy or metabolism-energy or metabolisms-energy or energy-balance or balance-energy or caloric-expenditure*).ti,ab.	438,295
2	Exercise/ or Sedentary Behavior/ or (physical-activit* or activities-physical or activity-physical or exercise* or free-living-activit* or sedentary-behavior* or behavior-sedentary or inactivity-physical or lack-of-physical-activity or lifestyle-sedentary or physical-inactivity or sedentary-behaviour* or sedentary-time* or time-sedentary or volume-of-activity or physical-activity-intensit* or MetS or metabolic-syndrome* or kcal* or total-activity-count*).ti,ab.	467,187
3	1 and 2	26,933
4	limit 3 to (english language and yr="2000 -Current")	19,391
5	limit 4 to "systematic review"	252
6	Wearable Electronic Devices/ or Accelerometry/ or Self Report/ or Calorimetry, Indirect/ or Oxygen Consumption/ or (wearable-electronic-device* or wearable-physical-activity-monitor* or device-wearable* or devices-wearable* or electronic-device-wearable* or electronic-devices-wearable* or electronic-skin* or skin-electronic or	

Search No.	Syntax	Results
	technologies-wearable or technology-wearable or wearable-device* or wearable-electronic-device* or wearable-technolog* or accelerometer* or accelerometr* or objective-measure* or subjective-measure* or self-report* or report-self or reports-self or diary or physical-activity-questionnaire* or calorimetry-indirect or calorimetries-indirect or calorimetries-respiration* or calorimetry-indirect or calorimetry-respiration or indirect-calorimetr* or respiration-calorimetr* or indirect-calorimeter* or portable-calorimeter* or room-calorimeter* or oxygen-consumption* or consumption-oxygen or consumptions-oxygen or VO2 or doubly-labeled-water).ti,ab.	
7	3 and 6	9,471
8	Limit 7 to (english language and yr="2000 -Current" and "systematic review")	64

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab,kw.	9
2	(physical-activity or activity-physical or exercise or biometric-exercise or effort or exercise-capacity or exercise-performance or exercise-training or exertion or fitness-training or fitness-workout or physical-conditioning-human or physical-effort or physical-exercise or physical-exertion or physical-work-out or physical-workout or free-living-activit* or sedentary-behavior* or sedentary-behaviour* or sedentary-lifestyle* or sedentary-life-style or volume-of-activit* or physical-activity-intensit* or MetS or metabolic-syndrome* or kcal* or total-activity-count*).ti,ab,kw.	739
3	1 and 2	5
4	(wearable-physical-activity-monitor* or accelerometer* or meter-accelero or objective-measure* or subjective-measure* or self-report* or diary or physical-activity-questionnaire* or indirect-calorimeter* or indirect-calorimetry or portable-calorimeter* or room-calorimeter* or oxygen-consumption* or consumption-oxygen or consumptions-oxygen or VO2 or doubly-labeled-water).ti,ab,kw	272
5	3 and 4	2

Key Question: What is the association between weight change and chronic disease outcomes?
Date: May 6, 2022

Search Parameters:
Date: 2017–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Medline (Ovid), Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid):

Search No.	Syntax	Results
1	exp body weight loss/ or exp body weight maintenance/ or exp body weight gain/ or exp body weight change/ or exp weight cycling/ or exp body weight fluctuation/ or (body-weight-loss or body-weight-decrease or body-weight-reduction or weight-decrease or weight-los* or weight-reduc* or weight-watch* or weight-maintenance or body-weight-gain* or body-weight-increase* or weight-gain* or weight-increase* or weight-change* or body-weight-change* or weight-cycling or yo-yo-diet* or yo-yo-effect* or yoyo-diet* or body-weight-fluctuation* or weight-fluctuation*).ti,ab.	310,134
2	*cardiovascular disease/ or *congenital heart disease/ or *non insulin dependent diabetes mellitus/ or *malignant neoplasm/ or *hypertension/ or *hip fracture/ or *all cause mortality/ or *dementia/ or (cardiovascular-disease* or angiocardiopathy or angiocardiovascular-disease* or cardiovascular-complication* or cardiovascular-disturbance* or cardiovascular-lesion* or cardiovascular-syndrome* or cardiovascular-vegetative-disorder* or complication-cardiovascular* or disease-cardiovascular or major-adverse-cardiovascular-event* or congenital-heart-disease* or congenital-cardiac-disease* or congenital-cardiac-distress* or congenital-heart-distress* or congenital-heart-failure* or heart-congenital-disease* or neonatal-cardiopathy or truncus-arteriosus-persistent* or adult-onset-diabetes or diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-type-2 or diabetes-type-II or diabetes-adult-onset or dm-2 or	4,226,771

Search No.	Syntax	Results
	insulin-independent-diabetes or ketosis-resistant-diabetes-mellitus or maturity-onset-diabetes or NIDDM or non-insulin-dependent-diabetes or non-insulin-dependent-diabetes-mellitus or noninsulin-dependent-diabetes or T2DM or type2-diabetes or type-II-diabetes or cancer* or malignant-neoplasia or malignant-neoplasm* or malignant-neoplastic-disease* or malignant-tumor* or malignant-tumour* or neoplasia-malignant or tumor-malignant or tumour-malignant or hypertension or blood-pressure-high or high-blood-pressure or high-renin-hypertension or hypertensive-disease* or hypertensive-effect* or hypertensive-effect* or hypertensive-response or hip-fracture* or broken-hip* or fracture-hip* or fractured-hip* or all-cause-mortality or dementia or amentia or demention).ti,ab.	
3	1 and 2	65,276
4	limit 3 to (english language and “systematic review” and yr=”2017 -Current”)	1,120

Medline (Ovid):

Search No.	Syntax	Results
1	exp Body Weight Changes/ or exp weight cycling/ or exp weight gain/ or exp weight loss/ or (body-weight-change* or change-body-weight or changes-body-weight or weight-change-body or weight-changes-body or weight-cycling or cycling-weight or gain-weight or gains-weight or weight-gain* or weight-loss or loss-weight or losses-weight or reduction-weight or reductions-weight or weight-loss* or weight-reduction*).ti,ab.	180,453
2	Cardiovascular Diseases/ or Heart Defects, Congenital/ or Diabetes Mellitus, Type 2/ or Neoplasms/ or Hypertension/ or Hip Fractures/ or Dementia/ or (cardiovascular-disease* or disease-cardiovascular or abnormality-heart or congenital-heart-defect* or congenital-heart-disease* or defect-congenital-heart or defects-congenital-heart or disease-congenital-heart or heart-abnormalit* or heart-defect-congenital or heart-defects-congenital or heart-disease-congenital or heart-malformation-of or malformation-of-heart* or adult-onset-diabetes-mellitus or diabetes-maturity-onset or diabetes-mellitus-adult-onset or diabetes-mellitus-	3,890,945

Search No.	Syntax	Results
	ketosis-resistant or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-mellitus-noninsulin-dependent or diabetes-mellitus-slow-onset or diabetes-mellitus-stable or diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-type-2 or ketosis-resistant-diabetes-mellitus or mody or maturity-onset-diabetes or maturity-onset-diabetes-mellitus or niddm or non-insulin-dependent-diabetes-mellitus or slow-onset-diabetes-mellitus or stable-diabetes-mellitus or type-2-diabetes or neoplasm* or cancer* or malignancies or malignancy or neoplasia* or tumor* or hypertension or blood-pressure-high or blood-pressures-high or high-blood-pressure* or fractures-hip or fractures-intertrochanteric or fractures-subtrochanteric or fractures-trochanteric or hip-fractures or intertrochanteric-fracture* or trochanteric-fracture* or all-cause-mortality or dementia* or amentia*).ti,ab.	
3	1 and 2	42,764
4	limit 3 to (english language and yr="2017 -Current" and "systematic review")	501

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	(body-weight-change* or change-body-weight or changes-body-weight or weight-change-body or weight-changes-body or weight-cycling or cycling-weight or gain-weight or gains-weight or weight-gain* or weight-loss or loss-weight or losses-weight or reduction-weight or reductions-weight or weight-loss* or weight-reduction*).ti,ab,kw.	279
2	(cardiovascular-disease* or disease-cardiovascular or abnormality-heart or congenital-heart-defect* or congenital-heart-disease* or defect-congenital-heart or defects-congenital-heart or disease-congenital-heart or heart-abnormalit* or heart-defect-congenital or heart-defects-congenital or heart-disease-congenital or heart-malformation-of or malformation-of-heart* or adult-onset-diabetes-mellitus or diabetes-maturity-onset or diabetes-mellitus-adult-onset or diabetes-mellitus-ketosis-resistant or diabetes-mellitus-maturity-onset or diabetes-mellitus-non-insulin-dependent or diabetes-mellitus-noninsulin-dependent or diabetes-mellitus-slow-onset or diabetes-mellitus-stable or	2,572

Search No.	Syntax	Results
	diabetes-mellitus-type-2 or diabetes-mellitus-type-ii or diabetes-type-2 or ketosis-resistant-diabetes-mellitus or mody or maturity-onset-diabetes or maturity-onset-diabetes-mellitus or niddm or non-insulin-dependent-diabetes-mellitus or slow-onset-diabetes-mellitus or stable-diabetes-mellitus or type-2-diabetes or neoplasm* or cancer* or malignancies or malignancy or neoplasia* or tumor* or hypertension or blood-pressure-high or blood-pressures-high or high-blood-pressure* or fractures-hip or fractures-intertrochanteric or fractures-subtrochanteric or fractures-trochanteric or hip-fractures or intertrochanteric-fracture* or trochanteric-fracture* or all-cause-mortality or dementia* or amentia*).ti,ab,kw.	
3	1 and 2	79
4	limit 3 to last 5 years	14

Key Question: What is the effect or association of weight cycling on metabolic efficiency (energy usage/expenditure) and health outcomes?
Date: February 23, 2022 (Search 1)

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Databases: Embase (Ovid) 1974 to 2022 February 22; Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid)

Search No.	Syntax	Results
1	*energy metabolism/ or *energy expenditure/ or *energy balance/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab.	103,565
2	exp weight cycling/ or (weight-cycling or yo-yo-diet* or yo-yo-effect* or yoyo-diet*).ti,ab.	573
3	1 and 2	52
4	limit 3 to (human and english language and yr="2000 -Current")	26
5	"systematic review"/ or systematic review*.mp.	434,492

Search No.	Syntax	Results
6	4 and 5	0

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	energy.ti,ab,kw.	124
2	(weight-cycling or yo-yo-diet* or yo-yo-effect* or yoyo-diet*).af.	9
3	1 and 2	0

Date: March 4, 2022 (Search 2)

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Database: Embase (Ovid), Cochrane Database of Systematic Reviews (Ovid), PubMed

Embase (Ovid):

Search No.	Syntax	Results
1	exp weight cycling/ or exp body weight fluctuation/ or (weight-cycling or yo-yo-diet* or yo-yo-effect* or yoyo-diet* or body-weight-fluctuation* or weight-fluctuation*).ti,ab.	1,015
2	limit 1 to (human and english language and yr="2000 -Current")	598
3	"systematic review"/	333,502
4	2 and 3	14

Cochrane Database of Systematic Reviews (Ovid):

Search No.	**Syntax**	**Results**
1	(weight-cycling or yo-yo-diet* or yo-yo-effect* or yoyo-diet* or body-weight-fluctuation* or weight-fluctuation*).ti,ab,kw.	1

PubMed:
(Weight cycling[mh] or body weight fluctuation[mh] or weight-cycling[tiab] or yo-yo-diet[tiab] or yo-yo-diets[tiab] or yo-yo-effect[tiab] OR yo-yo-effects[tiab] or yoyo-diet[tiab] or yoyo-diets[tiab] or body-

weight-fluctuation[tiab] or body-weight-fluctuations[tiab] or weight-fluctuation[tiab] or weight-fluctuations[tiab]) and systematic review[pt]
Limit: Humans, English
Results: 12

Key Question: What level of calorie intake is needed to produce weight gain in individuals with underweight? What amount of calorie intake (deficit) is necessary to produce weight loss in individuals with overweight or obesity? What level of calorie intake is needed to maintain weight across the weight spectrum?
Date: February 23, 2022

Search Parameters:
Date: 2000–Present
Document Type: Systematic reviews
Language: English
Databases: Embase (Ovid) 1974 to 2022 February 22; Cochrane Database of Systematic Reviews (Ovid)

Embase (Ovid)

Search No.	Syntax	Results
1	*energy metabolism/ or *energy expenditure/ or *energy balance/ or (energy-expenditure* or caloric-expenditure* or energy-metabolism or metabolism-energy or energy-balance or balance-energy).ti,ab.	103,565
2	exp caloric intake/ or (calorie-intake* or calory-intake* or dietary-energy or energy-intake* or intake-caloric*).ti,ab.	78,710
3	exp body weight loss/ or exp body weight maintenance/ or exp body weight gain/ or exp caloric restriction/ or (body-weight-loss or body-weight-decrease or body-weight-reduction or weight-decrease or weight-los* or weight-reduc* or weight-watch* or weight-maintenance or body-weight-gain or body-weight-increase or weight-gain or weight-increase or caloric-intake-restriction or calorie-restriction*).ti,ab.	306,354
4	1 and 2 and 3	3,085
5	limit 4 to (human and english language and yr="2000 -Current")	1,762
6	"systematic review"/ or systematic review*.mp.	434,492
7	5 and 6	58

Cochrane Database of Systematic Reviews (Ovid):

Search No.	Syntax	Results
1	energy.ti,ab,kw.	124
2	(calorie-intake* or calory-intake* or dietary-energy or energy-intake* or intake-caloric*).ti,ab,kw.	42
3	(body-weight-loss or body-weight-decrease or body-weight-reduction or weight-decrease or weight-los* or weight-reduc* or weight-watch* or weight-maintenance or body-weight-gain or body-weight-increase or weight-gain or weight-increase or caloric-intake-restriction or calorie-restriction*).ti,ab,kw.	279
4	1 and 2 and 3	22

Appendix E

Key Questions and Eligibility Criteria

Key Question: What is the association between body mass index (BMI) and chronic disease, including all-cause mortality?

Population	• Human only • General population (not existing disease state)
Interventions/ exposures and comparators	Body weight category (by BMI, W-score): overweight, obese, underweight, normal weight
Study designs (of primary studies included within the systematic reviews)	Include: • Longitudinal studies Exclude: • Cross-sectional studies Systematic reviews must include a meta-analysis
Timing	No minimum "treatment" or exposure duration required No minimum follow-up duration (to when outcome is measured)
Setting	Restrict to high- and upper middle-income countries Restrict to systematic reviews published 2017 or later

Outcomes	• Incident cardiovascular disease/coronary heart disease • Incident type 2 diabetes • Incident cancer • Incident hypertension • Incident hip fracture • All-cause mortality • Pregnancy-related • Maternal mortality • Preeclampsia • Infant mortality • Premature delivery • Pediatric • Growth

Key Question: What is the effect of BMI (and other measures of adiposity) on energy balance or energy expenditure?

Population	• Human only • Allow focus on health conditions: obesity, type 2 diabetes • Exclude focus on other health conditions • Allow focus on other population groups: o High physical activity o Diet type • Subgroups of interest o Age/life stage o Sex o Race/ethnicity
Interventions/exposures and comparators	• Body weight category (by BMI, W-score): overweight, obese, underweight, normal weight • Other measures of adiposity • Exclude any cointerventions/coexposures (e.g., low fat + vitamin B_{12} vs. high fat; physical activity)
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized crossover trials • Randomized clinical trials (parallel) • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/exposures) • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)

Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later
Outcomes	• Energy balance/imbalance/excess/deficit o Energy intake o Energy expenditure (TEE, REE, BMR, BEE, RMR) o Body weight o BMI • Energy utilization o Fat/carbohydrate/protein oxidation o Body fat o Body weight • Energy metabolism/metabolic efficiency/metabolic flexibility • Obesity risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat • Type 2 diabetes mellitus risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat o Glucose o Insulin o HOMA-IR • Cardiovascular Disease risk

NOTE: BEE = basal energy expenditure; BMI = body mass index; BMR = basal metabolic rate; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; REE = resting energy expenditure; RMR = resting metabolic rate.

Key Question: What is the association of body composition with metabolic efficiency (energy usage/expenditure)?

Population	• Human only • Exclude focus on other health conditions (e.g., malnourished population) • Allow focus on other population groups: o High physical activity o Diet (e.g., vegetarian, vegan) o Others (determined on a case-by-case basis) • Subgroups of interest o Age/life stage o Sex o Race/ethnicity • Study must provide separate results data by sex (or be specific to one sex)
Interventions/ exposures and comparators	• Exposure: fat mass vs. fat-free mass measured within the same individual • Within the exposure of interest, consider studies using DLW, DXA, and/or underwater weighing to estimate FM and FFM • Allow any cointerventions/coexposures (e.g., low fat + vitamin B_{12} vs. high fat; physical activity)
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized crossover trials (including N-of-1) • Randomized clinical trials (parallel) • Single group (noncomparative between interventions/ exposures) • Nonrandomized comparative studies, multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later
Outcomes	Usage/expenditure must be measured (e.g., DLW, direct and indirect calorimetry) • 24-hour energy expenditure • Resting or basal metabolic rate • Energy cost of physical activity • Thermic effect of food • Metabolic adaptation (mitochondria dynamics)

NOTE: DLW = doubly labeled water; DXA = dual-energy X-ray absorptiometry; FFM = fat-free mass; FM = fat mass.

Key Question: How does the increase in tissue deposition associated with growth during infancy, childhood, adolescence, pregnancy, and lactation influence, affect, or contribute to energy requirements?

Population	• Human only
	• Do not allow focus on health conditions or other population groups
	• Study must provide separate results data by sex (or be specific to one sex)
	• Study must provide separate results data by age group (or be specific to one age group or life stage)
	• Subgroups of interest
	  o Age/life stage
	  o Sex

Interventions/ exposures and comparators	The life stage of infancy, childhood, adolescence, pregnancy, and lactation
Study designs	Include: • Randomized clinical trials • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Nonrandomized comparative studies, multivariable adjusted • Longitudinal studies • Systematic reviews Exclude: • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 1980 or later

Outcomes	• Energy usage or energy expenditure o Measured by DLW, direct or indirect calorimetry • Growth during infancy, childhood, or adolescence o Measured by weight gain (anthropometry) and composition of gain (body composition techniques), energetic efficiency (encompassed by DLW; also estimated by theoretical biochemical efficiencies) • Pregnancy o Measured by rate of weight gain per trimester (anthropometry) and composition of gain (body composition techniques); energy efficiency (encompassed by DLW) • Lactation o Measured by volume of milk production and proximate analysis of milk (fat, protein, carbohydrate) or energy content of milk (bomb calorimetry); energy efficiency (encompassed by DLW)

NOTE: DLW = doubly labeled water

Key Question: What is the impact of race or ethnicity on energy expenditure?

Population	• Human only • Subgroups of interest o Age/life stage o Sex
Interventions/ exposures and comparators	Race or ethnic group
Study designs (of primary studies included within the systematic reviews and primary studies)	• Randomized clinical trials • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to systematic reviews published 2012 or later • Restrict to primary studies published 1980 or later

Outcomes	• BMR • RMR • BEE • REE • Energy metabolism • Energy expenditure • Energy balance • Caloric expenditure

NOTE: BEE = basal energy expenditure; BMR = basal metabolic rate; REE = resting energy expenditure; RMR = resting metabolic rate.

Key Question: What is the association of macronutrient composition of the diet on metabolic efficiency (energy usage/expenditure)?

Population	• Human only
	• Allow focus on health conditions: obesity or type 2 diabetes
	  o Exclude focus on other health conditions
	• Allow focus on other population groups:
	  o High physical activity
	  o Diet (e.g., vegetarian, vegan)
	  o Others (determined on a case-by-case basis)
	• Subgroups of interest
	  o Age/life stage
	  o Sex
	  o Race/ethnicity

Interventions/ exposures and comparators	Diets with different macronutrient composition • High fat vs. low protein (holding carbohydrates stable with comparator) • High fat vs. low carbohydrate (holding protein stable with comparator) • Low fat vs. high protein (holding carbohydrates stable with comparator) • Low fat vs. high carbohydrate (holding protein stable with comparator) • High protein vs. low carbohydrate (holding fat stable with comparator) • Low protein vs. high carbohydrate (holding fat stable with comparator) • Within the intervention/exposure of interest, exclude if diets not isocaloric

Study designs (of primary studies included within the systematic reviews)	Include: • Randomized crossover trials (including N-of-1) • Randomized clinical trials (parallel) • Single group (noncomparative between interventions/ exposures) • Nonrandomized comparative studies, multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later
Outcomes	Usage/expenditure must be measured (e.g., DLW, direct and indirect calorimetry) • 24-hour energy expenditure • Resting or basal metabolic rate • Energy cost of physical activity • Thermic effect of food • Metabolic adaptation (mitochondria dynamics)

NOTE: DLW = doubly labeled water.

Key Question: In the U.S. and Canadian free-living population, what is the degree of systematic bias or random error of energy intake as assessed by diet records, 24-hour recalls, food frequency questionnaires, compared to doubly labeled water? Does the bias differ by age group, sex, body weight status, body mass index (BMI), social economic status, race, ethnicity, presence of chronic disease, or physical activity level?

Population	• Human only • Allow focus on health conditions: obesity, type 2 diabetes • Allow focus on other population groups: o High physical activity o Diet (e.g., vegetarian, vegan) • Subgroups of interest o Age/life stage o Sex o Race/ethnicity • Study must provide separate results data by age group (or be specific to one age group/life stage).

Interventions/ exposures and comparators	Participation in a doubly labeled water study measuring usual dietary intake
Study designs (of primary studies included within the systematic reviews)	• Randomized clinical trials • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high-income countries • Restrict to systematic reviews published 2012 or later
Outcomes	Percent of misreporting of energy intakes

Key Question: How do physical activity and energy expenditure change across the life span?

Population	• Human only
	• Allow focus on health conditions: obesity, type 2 diabetes
	  o Exclude focus on other health conditions
	• Allow focus on other population groups:
	  o High physical activity
	  o Diet (e.g., vegetarian, vegan)
	• Subgroups of interest
	  o Age/life stage
	  o Sex
	  o Race/ethnicity

Interventions/ exposures and comparators	Different age or age categories
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized clinical trials • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted

Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restricted to studies published 2000 or later
Outcomes	• Physical activity o Kcals o METs o Physical activity intensity (light, moderate, vigorous) o Sedentary behaviors o Steps o Total activity counts o Volume o Activity type o Behavior • Energy expenditure o Total energy expenditure o Net energy expenditure o Activity energy expenditure o Energy cost of physical activity • Type of measurement o Doubly labeled water o Accelerometer o Wearable sensors o Questionnaire o Objective o Subjective o Indirect calorimetry o Room calorimeter o Free living • Obesity risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat

NOTE: BMI = body mass index; kcals = kilocalories; METs = metabolic equivalent of task.

Key Question: What is the relationship between different measurements of physical activity and energy expenditure?

Population	• Human only
	• Allow focus on health conditions: obesity, type 2 diabetes
	  o Exclude focus on other health conditions
	• Allow focus on other population groups:
	  o High physical activity
	  o Diet (e.g., vegetarian, vegan)
	• Subgroups of interest
	  o Age/life stage
	  o Sex
	  o Race/ethnicity

Interventions/ exposures and comparators	Physical activity measurement method
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized clinical trials • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later

Outcomes	• Physical activity
	  o Kcals
	  o METs
	  o Physical activity intensity (light, moderate, vigorous)
	  o Sedentary behaviors
	  o Steps
	  o Total activity counts
	  o Volume
	  o Activity type
	  o Behavior

Outcomes *continued*	• Energy expenditure
	  o Total energy expenditure
	  o Net energy expenditure
	  o Activity energy expenditure
	  o Energy cost of physical activity
	• Type of measurement
	  o Doubly labeled water
	  o Accelerometer
	  o Wearable sensors
	  o Questionnaire
	  o Objective
	  o Subjective
	  o Indirect calorimetry
	  o Room calorimeter
	  o Free living
	• Obesity risk
	  o Body weight
	  o BMI
	  o Body fat %
	  o Waist circumference
	  o Visceral fat

NOTE: BMI = body mass index; kcals = kilocalories; METs = metabolic equivalent of task.

Key Question: What is the association between weight change and chronic disease outcomes?

Population	• Human only
	• General population (not existing disease state)
	  o Adults, including postpartum women (lactating or not) as a subpopulation of interest
	  o Children

Interventions/ exposures and comparators	• Body weight change (weight cycling, weight gain, weight loss, postpartum weight gain/retention). May include weight maintenance or slowed weight gain o Weight must be measured (not self-reported) • Exclude studies focused on unintentional weight loss and studies of bariatric surgery outcomes
Study designs (of primary studies included within the systematic reviews)	Include: • Longitudinal studies (adults) • Cohort studies (adults) • Randomized clinical trials of weight loss interventions Exclude: • Cross-sectional studies
Timing	• Cohort studies: at least 12 months of follow-up • Randomized clinical trials: at least 3 months of intervention
Setting	• Restrict to high- and upper middle-income countries • Restrict to systematic reviews published 2017 or later

Outcomes	• Incident cardiovascular disease/coronary heart disease • Incident type 2 diabetes • All-cause mortality • Incident hypertension • Incident cancer (adults) • Incident hip fracture (adults) • Dementia (adults) • cardiovascular disease risk factors (children) • Metabolic syndrome or prediabetes (children)

Key Question: What is the effect or association of weight cycling on metabolic efficiency (energy usage/expenditure) and health outcomes?

Population	• Human only
	• Allow focus on health conditions: obesity, type 2 diabetes
	  o Exclude focus on other health conditions
	• Allow focus on other population groups:
	  o High physical activity
	  o Diet type
	• Subgroups of interest
	  o Age/life stage
	  o Sex
	  o Race/ethnicity

Interventions/ exposures and comparators	Weight cycling Exclude any cointerventions/coexposures (e.g., low fat + vitamin B_{12} vs. high fat; physical activity)
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized crossover trials (including N-of-1) • Randomized controlled trials (parallel) • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later

Outcomes	• Energy balance/imbalance/excess/deficit o Energy intake o Energy expenditure (TEE, REE, BMR, BEE, RMR) o Body weight o BMI • Energy utilization o Fat/carbohydrate/protein oxidation o Body fat o Body weight • Body composition o Lean mass o Fat mass o Body fat % o Body weight • Energy metabolism/metabolic efficiency/metabolic flexibility • Obesity risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat [a] Type 2 diabetes mellitus risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat o Glucose o Insulin o HOMA-IR

NOTE: BEE = basal energy expenditure; BMI = body mass index; BMR = basal metabolic rate; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; REE = resting energy expenditure; RMR = resting metabolic rate.

Key Questions:
What level of calorie intake is needed to produce weight gain in individuals with underweight? What amount of calorie intake (deficit) is necessary to produce weight loss in individuals with overweight or obesity? What level of calorie intake is needed to maintain weight across the weight spectrum?

Population	• Human only • Allow focus on health conditions: obesity, type 2 diabetes • Allow focus on other population groups: o High physical activity o Diet (e.g., vegan, vegetarian) • Subgroups of interest o Age/life stage o Sex o Race/ethnicity
Interventions/ exposures and comparators	Measure of caloric intake Exclude any cointerventions/coexposures (e.g., low fat + vitamin B_{12} vs. high fat; physical activity)
Study designs (of primary studies included within the systematic reviews)	Include: • Randomized crossover trials • Randomized clinical trials • Nonrandomized comparative studies, multivariable adjusted • Association analyses (e.g., regression models, predictors, risk factors), multivariable adjusted Exclude: • Nonrandomized comparative studies, unadjusted • Single group (noncomparative between interventions/ exposures) • Association analyses (e.g., models, predictors, risk factors), univariate, unadjusted • Other study designs
Timing	• No minimum "treatment" or exposure duration required • No minimum follow-up duration (to when outcome is measured)
Setting	• Restrict to high- and upper middle-income countries • Restrict to studies published 2000 or later

Outcomes	[a] Energy balance/imbalance/excess/deficit o Energy intake o Energy expenditure (TEE, REE, BMR, BEE, RMR) o Body weight o BMI • Energy use o Fat/carbohydrate/protein oxidation o Body fat o Body weight • Energy metabolism/metabolic efficiency/metabolic flexibility • Obesity risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat • Type 2 diabetes mellitus risk o Body weight o BMI o Body fat % o Waist circumference o Visceral fat o Glucose o Insulin o HOMA-IR

NOTE: BEE = basal energy expenditure; BMI = body mass index; BMR = basal metabolic rate; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; REE = resting energy expenditure; RMR = resting metabolic rate.

Appendix F

AMSTAR 2 Tool

During the data extraction process of the umbrella review, the methodological quality of each systematic review was evaluated using the Assessment of Multiple Systematic Reviews 2 (AMSTAR 2) quality assessment tool, with some minor adaptations for clarity. The tool consists of the following series of 15 questions. Alterations to or interpretations of the tool made by the committee are noted in italic text.

(1) Did the research questions and inclusion criteria for the review include ALL the components of PICO?
- Yes: Population, Intervention, Comparator, Outcome, AND Follow-up duration *described fully and adequately.*
- *Partial: Described, but not adequately to sufficiently understand eligibility criteria [Partial was added by the committee].*
- No: Not all PICO elements

(2) Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review, and did the report justify any significant deviations from the protocol?
- Partial: Protocol included "just" (1) review questions, (2) search strategy, (3) eligibility criteria, AND (4) risk of bias assessment [and/or PROSPERO or other registry].
- Yes: Protocol included all Partial, PLUS (5) meta-analysis or synthesis plan, (6) plan to investigate heterogeneity, AND (7) justifications for deviation from protocol.

- No: Not all criteria met (for Partial) or no mention of a protocol
  - *Study authors were given the benefit of the doubt in edge cases.*

(3) Did the review authors explain their selection of the study designs for inclusion in the review?
- Yes: Provided explanation for selecting study designs (and for not selecting excluded study designs)
- No: No explanation
  - *Study authors were given the benefit of the doubt in edge cases. Implicit explanations were acceptable.*

(4) Did the authors use a comprehensive literature search strategy?
- Partial: (1) at least two relevant databases, (2) provided key words or search strategy, AND (3) justified restrictions (e.g., language) *OR arbitrarily excluded studies (e.g., based on perceived risk of bias) [latter item added by the committee]*
- Yes: all Partial PLUS (4) searched reference lists, (5) searched study registries, *OR* (6) consulted content experts *[Note: AMSTAR 2 says "AND" here]*
- No: Not all criteria met (for Partial) *OR used a clearly inadequate search strategy. [The latter two reasons were added by the committee.]*

(5) Did the review authors perform study selection in duplicate?
- Yes: At least two independent screeners, plus a method for reconciling conflicts OR double screening of a sample with at least 80% agreement, followed by single screening *[Note: Committee combined original Yes and Partial into simply Yes.]*
- No: Less stringent method used.

(6) Did the review authors perform data extraction in duplicate?
- Yes: Double independent with reconciliation process OR Single with review by experienced systematic reviewer
- No: Less stringent method used
  - *We gave researchers the benefit of the doubt regarding their systematic review experience.*

(7) Did the review authors provide a list of excluded studies and justify the exclusions?
- Yes: Listed and provided exclusion for each *OR reported available access to such a list [Note: Committee added the second option here.]*
- Partial: Listed but did not explain each exclusion
- No: Did not list

(8) Did the review authors describe the included studies in adequate detail?
Partial: Described "just" each PICOD element *OR the studies were described, but with some limitations for the needs of the committee [Note: Committee added the second option here.]*

- Yes: Described PICOD elements in detail, including setting and follow-up time *OR the descriptions of the studies were sufficient for the needs of the committee [Note: Committee added the second option here.]*
- No: Partial not met

(9) Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?

- Yes: Used a standard risk-of-bias tool (e.g., Cochrane Risk of Bias tool for randomized trials, ROBINS-I for nonrandomized studies) or equivalent tool that addresses relevant issues related to randomization/allocation concealment, confounding bias, selection bias, outcome ascertainment, analytic method
    - *This framework is based on the concepts described by AMSTAR 2.*
- Partial: Used an appropriate tool but applied an arbitrary point system to determine level of quality/risk of bias
    - *This revision was added, post hoc, upon reviewing eligible systematic reviews.*
- No: No or inadequate risk-of-bias tool applied

(10) Did the review authors report on the sources of funding for the studies included in the review?

- Yes
- No

(11) If meta-analysis was performed, did the review authors use the appropriate methods for the statistical combination of results?

- Yes: (1) Justified combining in meta-analysis, (2) used random effects model (or equivalent), AND (3) analyzed heterogeneity
    - *Committee removed concepts related to whether unadjusted analyses were included and whether studies of different designs were combined.*
- *No: (1) Used fixed-effect model (or equivalent) based on heterogeneity measures OR (2) conducted meta-regression or subgroup analysis subject to ecological fallacy (i.e., regressed across the mean value for the sample, such as BMI)*

    If there were concerns regarding fixed-effect models or ecological fallacy, the relevant analyses were highlighted. The committee did not derive conclusions based on analyses subject to ecological fallacy.

(12) Did the review authors account for RoB in individual studies when interpreting/discussing the results of the review?

- Yes
- No

(13) Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?
- Yes: Heterogeneity was assessed AND, if present, assessed causes and included as part of their interpretation of findings.
- No: Did not assess heterogeneity OR only enumerated without assessing the impact on findings

(14) If they performed quantitative synthesis, did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?
- Yes: *Reported* and carried out plan to assess publication bias *[Note: The committee required reporting of a plan to assess publication bias.]*
- No: Did not report plan to assess publication bias

(15) Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?
- Yes
- No

OVERALL "QUALITY"

The system for determining the quality, or methodological adequacy, of the systematic reviews was constructed by the committee based on concepts and terminology from AMSTAR 2. While all AMSTAR 2 questions were answered, not all impacted the overall quality.

Well-done/reported systematic reviews

- (1) Adequately reported PICO [Yes, not Partial], (2) had a protocol [Yes, Partial], (4) used a comprehensive literature search [Yes, not Partial], (5) selected studies in duplicate [Yes], (6) extracted studies in duplicate or equivalent [Yes], (8) adequately described studies [Yes], (9) assessed risk of bias [Yes, Partial], (11) used appropriate meta-analysis techniques if applicable [Yes], (12) accounted for risk of bias [Yes], (13) assessed heterogeneity [Yes], and (15) reported sources of conflict of interest [Yes]
- *Did not require (3) explanation of selected study designs, (7) listing of excluded studies, (10) reporting of sources of funding for included studies, OR (14) assessment of publication bias.*

Partially well-done/reported systematic reviews

Studies were downgraded to Partially well-done/reported if

- (1) Partially adequate reporting of PICO [Partial], (2) did not report a protocol [No], (4) partially adequate literature search [Partial], (6) did not extract in duplicate or equivalent [No/Unclear], (8) did not adequately describe studies [Partial/No], (13) did not adequately assess heterogeneity [No], OR (15) did not report conflicts of interest.

Not well-done/reported systematic reviews

Studies were downgraded to Not well-done/reported if

- (1) Inadequate reporting of PICO [No], (4) inadequate literature search [No], (5) did not select studies in duplicate [No], (9) did not assess risk of bias [No], (11) used inappropriate meta-analysis technique [No; this may apply only to selected conclusions/findings within the systematic review], OR (12) did not account for risk of bias [No].

Appendix G

Data Analysis Report

DATA ANALYSIS REPORT

Data Analysis for the Committee to Review the DRIs for Energy

October 19, 2022
Indiana University, School of Public Health – Bloomington

Dean David Allison, Dean and Distinguished Professor, Provost Professor, Department of Epidemiology & Biostatistics
Dr. Carmen Tekwe, Associate Professor, Department of Epidemiology & Biostatistics
Dr. Roger Zoh, Associate Professor, Department of Epidemiology & Biostatistics
Stephanie Dickinson, Executive Director, Biostatistics Consulting Center
Lilian Golzarri Arroyo, Biostatistician II, Biostatistics Consulting Center
Aaron Cohen, Biostatistician I, Biostatistics Consulting Center
Jocelyn Mineo, Research Associate, Biostatistics Consulting Center

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Introduction and Summary of Work

The team at Indiana University (IU), School of Public Health-Bloomington, was engaged to perform statistical analysis to derive equations for the estimation of energy expenditure in the general human population, including pregnant and lactating women in the USA and Canada, based on data collected across multiple studies using the doubly labeled water (DLW) method for measuring Total Energy Expenditure (TEE) under free-living conditions.

Four primary sources of data were sought:

1. Institute of Medicine (IOM)'s 2002/2005 Report[1] for Dietary Reference Intakes (DRIs) for Macronutrients,
2. International Atomic Energy Agency (IAEA),
3. Study of Latinos: Nutrition and Physical Activity Assessment Study (SOLNAS) data from the National Heart, Lung and Blood Institute (NHLBI) Biologic Specimen and Data Repository,
4. Harvard Men's Lifestyle Study.

Data were obtained from IOM, IAEA, and SOLNAS as described below; however, data were not obtained from Harvard Men's Lifestyle Study in time for inclusion in this report. An additional data source was added for pregnancy data from the Children's Nutrition Research Center (CNRC) to increase the sample sizes for pregnant and lactating women.

The first task was to request data from the relevant sources, preparing Data Use Agreements (DUAs) as needed, including lists of the specific variables requested, including TEE, Basal Energy Expenditure (BEE; or basal metabolic rate [BMR]), age, sex, height, weight, body composition, physical activity, health status, athletic status, and country codes. The IU team then worked diligently to harmonize variable names, recode classifications, and combine these across data sets, resulting in 8,600 observations (cases) in the pooled data set.

Multiple tables of descriptive statistics and visualizations were provided for each dataset to allow Workgroup 1 (WG1) of the DRI energy committee to thoroughly inspect the data.

One challenge for the IU team was to consider how to perform predictive modeling of TEE based on physical activity level (PAL) while PAL (=TEE/BEE) was missing for 54.2% of the data (4,662 out of 8,600) where BEE was unavailable. Multiple Imputation was selected as the best method to impute the data rather than simple estimates of BEE (or more

[1] IOM (Institute of Medicine). 2002/2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*+Washington, DC: The National Academies Press.

accurately, BMR) based on age, sex, and weight in equations such as that published by Schofield[2] or others.

Additional work between IU and WG1 involved physical activity data and to consider how PAL should be included in predictive equations of TEE. Initial models used the same cutoff criteria and model forms used in the 2002/2005 IOM report, but methods were revised to use different PAL criteria, which vary by age groups per discussion with WG1, as described below.

Prediction equations were then developed by fitting linear models on TEE based on sex, age, PAL, weight, height, and body composition. Multiple imputation was used to estimate PAL across 20 versions of imputed data, where models were fit to each of the 20 imputations, and the results were pooled to identify final parameter estimates and standard errors (SEs) as defined by Rubin.[3]

Models were fit for the overall sample and were then separated by including different Body Mass Index (BMI [kg/height or length]^2) groups: BMI 18.5 to 40 (removing extremes); BMI 18.5 to 25 ("healthy" only); and BMI 25+ (overweight/obese only) to compare how regression slopes may differ by weight status groups.

The prediction of TEE with models using height and weight were also compared to those with height, fat-free mass (FFM), and fat mass (FM).

Models were fit separately in 7 strata:

- Infant/Toddler Boys (0–2.99 years old),
- Infant/Toddler Girls (0–2.99 years old),
- Boys (3.0–18.99 years old),
- Girls (3.0–18.99 years old),
- Men (19 and over),
- Women (19 and over),
- Pregnant

Model validation was performed on the external data (described below) provided by WG1 as summary data extracted from the literature. Parameter estimates from the TEE equations developed on the main data set were used to calculate predicted values of TEE on the external data, and those predicted values were compared to the observed TEE values using measures such as *R*-squared and correlation as a measure of model fit and performance.

2. IAEA DATA PREPARATION

IAEA data were obtained by submitting an application to the database manager (Dr. John Speakman) for the IAEA's doubly labelled water

[2] Schofield, W. N. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 39(Suppl 1):5-41.

[3] Rubin, D. B. 1987. *Multiple imputation for nonresponse in surveys*. New York: John Wiley & Sons.

database (https://doubly-labelled-water-database.iaea.org/). After the proper procedures and approval process from the database manager group, the data were transferred to Dr. Allison and his team in an Excel file "IAEA DLW database 3.6.1 abbreviated for DRI group (allison).xlsx".

Additional documents used for the data preparation of the IAEA data:

- "IAEA publications description IU 060722 - LGA notes.xlsx"—A list of studies to include or remove as indicated by WG1
- "CLASS 2022-06-13.xlsx"—Categories of Income by Country to indicate high-income countries for inclusion, provided by WG1
- Growth charts downloaded from https://www.cdc.gov/growthcharts/index.htm:
    - "Weightolength_WHO.xlsx"—Percentiles for weight-for-length for infants (0–2) per World Health Organization (WHO)
    - "BMIcharts.xlsx"—BMI percentiles for children (2–18) per Centers for Disease Control and Prevention (CDC)

The first step in preparation of the data was to apply the exclusion/inclusion criteria defined by WG1:

1. The International Organization for Standardization (ISO) codes found in the "CLASS 2022-06-13.xlsx" file were used to exclude all studies being done in non-high-income countries.
2. The codes under the column "Health" in the DLW database were used to include subjects who were healthy, labeled as H. Subjects with a code beginning with a D, such as D1 or D15 were excluded.
3. Professional athletes were removed from the data set by excluding those listed as PA in the 'ath' column.
4. Ineligible studies were removed according to the Excel file "IAEA publications description IU 060722," which WG1 highlighted yellow or indicated in workgroup meetings, for which IU coded as "1" in the Excel file in a column "Remove" to remove via SAS code. Those coded as "2" indicated special cases, which were inspected manually to exclude low-income countries or non-healthy participants.

After ineligible studies were removed, pregnant and lactating females were identified in order to be analyzed separately from other females in the study and coded for trimester and number of weeks of gestation or in the postpartum period, as follows:

Reproductive Status for Females (rep_statF)

- L=Lactating

  - Most 2020 study[4] was coded as 25 weeks
  - Motsiko study[5] was coded as 12 weeks
- P1=Pregnant, 1st trimester (This did not exist in IAEA data after preparation steps above.)
- P2=Pregnant, 2nd trimester
- P3=Pregnant, 3rd trimester

Next, while fat mass percentage (FM_pct) was provided in the IAEA data, fat mass (FM) was calculated as:

FM=(FM_pct/100*FFM)/(1-FM_pct/100).

TABLE 1 Inclusion and Exclusion Criteria and Sample Size for the IAEA Data Set

IAEA Inclusion/Exclusion	*N*
Read in the data	7,696
Only keep High-Income Countries	6,989
Remove any subject with a Health Code beginning with D	6,744
Remove Professional Athletes (PA) from PA category	6,706
Remove other ineligible studies	5,966
Remove those without age or sex	5,805
Remove participants with PAL < 1 or > 2.5 as defined in section 6.3.	5,717

Based on the above, two analysis-ready data files were created:

1. one including the 5,805 participants for preliminary descriptive statistics and visualizations before PAL exclusions ("IAEA"), and
2. one with the 5,717 for final analysis ("IAEA_clean").

3. IOM DATA PREPARATION

IOM data were obtained by extracting data from the pdf versions of the data listed in the appendix of the IOM's 2005 publication[6] and then converting into Excel.

[4] Most, J., A. D. Altazan, M. St Amant, R. A. Beyl, E. Ravussin, and L. M. Redman. 2020. Increased energy intake after pregnancy determines postpartum weight retention in women with obesity. *Journal of Clinical Endocrinology and Metabolism* 105(4):e1601-1611.

[5] Matsiko, E., P. J. M. Hulshof, L. van der Velde, M. F. Kenkhuis, L. Tuyisenge, and A. Melse-Boonstra. 2020. Comparing saliva and urine samples for measuring breast milk intake with the ^2H oxide dose-to-mother technique among children 2-4 months old. *British Journal of Nutrition* 123(2):232-240.

[6] Institute of Medicine. 2005. *Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10490.

The following data sets were read in for IOM data:

- "IOM2005_AppendixI_Tables_JM_LGA.xlsx" extracted from "IOM.2005.DRIs for Macronutrients.pdf"
  - TABLE I-1 Infants and Very Young Children (0 Through 2 Years of Age) Within the 3rd to 97th Percentile for Body Mass Index (BMI)
  - TABLE I-2 Normal Weight Children, 3 Through 18 Years of Age with Body Mass Index (BMI) > 85th Percentile
  - TABLE I-3 Normal Weight Adults with Body Mass Index (BMI) from 18.5 up to 25 kg/m^2
  - TABLE I-4 Pregnant Women with Prepregnancy Body Mass Index (BMI) from 18.5 up to 25 kg/m^2
  - TABLE I-5 Lactating Women with Prepregnancy Body Mass Index (BMI) from 18.5 up to 25 kg/m^2
  - TABLE I-6 Overweight/Obese Children, 3 Through 18 Years of Age, with Body Mass Index (BMI) > 85th Percentile
  - TABLE I-7 Overweight/Obese Adults with Body Mass Index (BMI) > 25 kg/m^2

Gestation weeks in IOM Table I-4 were grouped into trimester (P_stage), and lactation months in I-5 were grouped into 1–3 and 4–6 months postpartum.

TABLE 2 Inclusion and Exclusion Criteria and Sample Size for the IOM Data Set

IOM Inclusion/Exclusion	*N*
Read in Table I-1	320
Read in Table I-2	525
Read in Table I-3	407
Read in Table I-4	22
Read in Table I-5	35
Read in Table I-6	319
Read in Table I-7	360
Additional Combined Pregnancy Lactation Data	382
Merge all tables together	2313
Remove participants with PAL < 1 or > 2.5 as defined in section 6.3	2283

Based on the above, two analysis-ready data files were created:

1. one including the 2,313 participants for preliminary descriptive statistics and visualizations before PAL exclusions ("IOM"), and
2. one including the 2,283 for final analysis ("IOM_clean").

4. CNRC DATA PREPARATION

The following data set was provided by WG1 and read in for the Children's Nutrition Research Center at Baylor College of Medicine (CNRC):

- "CNRC Pregnancy w weeks 2022-08-20.xlsx"

Data include the number of weeks pregnant and weeks of lactation postpartum. Non-pregnant and non-lactating (NPNL) are also included, which were coded as weeks=0 for analysis.

The data set included 222 observations across 60 women (with three or four time points per women at preconception, second and third trimesters and six months postpartum)

TABLE 3 Inclusion and Exclusion Criteria and Sample Size for the CNRC Data Set

CNRC Inclusion/Exclusion	*N*
Source data from CNRC	222
Remove participants with PAL < 1 or > 2.5 as defined in section 6.3	220

Based on the above, two analysis-ready data files were created:

1. one including the 222 participants for preliminary descriptive statistics and visualizations before PAL exclusions ("CNRC"), and
2. one including the 220 for final analysis ("CNRC_clean").

5. SOLNAS DATA PREPARATION

DLW and physical activity data were obtained for Hispanic adults (19+) from The Study of Latinos: Nutrition & Physical Activity Assessment Study (SOLNAS) from the National Heart, Lung, and Blood Institute (NHLBI) BioLINCC site (https://biolincc.nhlbi.nih.gov/studies/hchssol/).

The following SAS data sets were read in for SOLNAS data:

- mysolnas.dlwa_lad1.sas7bdat
- mysolnas.vsea_lad1.sas7bdat
- mysolnas.biea_lad1.sas7bdat
- mysolnas.csea_lad1.sas7bdat

For the DLW data set (DLWA), only urine data were kept for TEE. The following variables were renamed according to the SOLNAS codebook.

TEE = DLWA33
BMI = DLWA34
FFM = DLWA35
FM = DLWA36
FM_pct = DLWA37

Height and weight were obtained from the main study visit 1 and visit 3 forms (VSEA) data set, and renamed as follows:

Height = VSEA3A
Weight = VSEA3B

For the body image (BIEA) data, data were only kept from the main study for gender, and the following variables were defined according to the codebook:

```
if BIEA1=1 then Sex = 'M';
if BIEA1=2 then Sex = 'F';
```

For the calorimetry summary (CSEA) data, data were kept from the main study for age and calorimeter weight, and the following variables were renamed:

Weight_calorim = CSEA2
Age = CSEA3
EE_mean_kcald= CSEA4D1
EE_SD_kcald= CSEA4D2
EE_CV_kcald= CSEA4D3

The variable 'EE_mean_kcald' was relabeled as 'BEE.'

The ethnicity for all participants in this study was coded as 'Hispanic,' and none of the participants were pregnant or lactating.

Physical activity data were also explored where 69 subjects had physical activity data from Actical. We used the "Actical derived variables at the participant level" data set for minutes per day of sedentary, light, moderate, and vigorous activity to correlate with PAL from DLW data.

TABLE 4 Inclusion and Exclusion Criteria and Sample Size for the SOLNAS Data Set

SOLNAS Inclusion/Exclusion	*N*
Merge data sets for DLW, VSEA, BIEA, CSEA	393
Remove those without age or sex	382
Remove participants with PAL < 1 or > 2.5 as defined in section 6.3	380

Based on the above, two analysis-ready data files were created:

1. one including the 382 participants for preliminary descriptive statistics and visualizations before PAL exclusions ("SOLNAS"), and
2. one including the 380 for final analysis ("SOLNAS_clean").

6. COMBINED DATA

The data sets from IAEA, IOM, SOLNAS, and CNRC pregnancy were harmonized to use consistent variable names and then combined. Variables are described in Appendix N: DLW Data Codebook.

SID, Age_cat, Age, Life_Stage, Ethnicity, Sex, BMI, BMIcat, Height, Weight, TEE, BEE, Percentile, Percentile_group, Percentile_infant, Lactating, Pregnant, P_stage, Weeks, PAL, PALCAT, BMR_kcal_Schofield, PAL_est, PALCAT_est, FFM, FM, FM_pct.

The combined data set included 8,722 participants for preliminary descriptive statistics and visualizations before PAL exclusions and 8,600 observations after removing participants with PAL < 1 or > 2.5 as defined in section 6.3.

Data coding and preparations were performed as follows:

6.1 Age Categories

Age categories were defined as follows for descriptive statistics reports, according to "Life Stage" as indicated by WG1:

- Infants are 0 to 11.99 months
- Children are 12.0 months to 8.99 years
- Teenagers are 9.0 to 18.99 years
- Adults are 19.0 years to 101 years

However, the following age categories were used for strata for the final TEE models:

- Infants are 0 to 2.99 years
- Children are 3.0 to 18.99 years
- Adults are 19.0 years and above

6.2 PAL Categories

The IOM 2005 report previously classified people into physical activity categories using roughly 25th, 50th, and 75th quartiles of PAL values uniformly across all age groups:

If 1.0=<PAL<1.4 then PALCAT=Sedentary[7]
If 1.4=<PAL<1.6 then PALCAT=Low Active
If 1.6=<PAL<1.9 then PALCAT=Active
If 1.9=<PAL<2.5 then PALCAT=Very Active

Here, we used the same quartiles (25th, 50th, 75th) to group people into the four categories, where the workgroup decided to calculate quartiles separately within age groups: 3 to 8.99 years, 9 to 13.99 years, and 14 to 18.99 years. For adults, PAL categories were defined by the quartiles for 19 to 70 years, but these PAL categories were applied to all adults, including those aged 71 and greater.

PAL percentiles as calculated on the raw data (before imputation) are shown in Appendix P §4.10 as well as after multiple imputation as shown in Appendix Q §2.1 and also in results section below.

After inspecting the PAL percentiles by age groups (shown below), PAL categories were defined by WG1 accordingly, and categories (PALCAT) were calculated in the SAS code as follows:

[7] Note that the term "Sedentary" and PALCAT="S" is used in this report as well as the analytic code and output, according to the labels in the 2005 IOM report before the committee relabeled the lowest level as "inactive."

```
If 3.0=<age<9.0 then do;

        If 1.0=<PAL<1.31 then PALCAT="S";
        If 1.31=<PAL<1.44 then PALCAT="LA";
        If 1.44=<PAL<1.59 then PALCAT="A";
        If 1.59=<PAL<2.5 then PALCAT="VA";
end;

If 9.0=<age<14.0 then do;
        If 1.0=<PAL<1.44 then PALCAT="S";
        If 1.44=<PAL<1.59 then PALCAT="LA";
        If 1.59=<PAL<1.77 then PALCAT="A";
        If 1.77=<PAL<2.5 then PALCAT="VA";
end;

If 14.0=<age<19.0 then do;
        If 1.0=<PAL<1.56 then PALCAT="S";
        If 1.56=<PAL<1.73 then PALCAT="LA";
        If 1.73=<PAL<1.92 then PALCAT="A";
        If 1.92=<PAL<2.5 then PALCAT="VA";
end;

If 19.0>=age then do;
*Note that these are based on percentiles of 19 to 70.99, but 71+
use these too;
        If 1.0=<PAL<1.53 then PALCAT="S";
        If 1.53=<PAL<1.68 then PALCAT="LA";
        If 1.68=<PAL<1.85 then PALCAT="A";
        If 1.85=<PAL<2.5 then PALCAT="VA";
end;
```

6.3 Data Screening

Because a PAL > 2.5 is considered unsustainable, participants with PAL > 2.5 were removed from analysis. A PAL < 1 is considered unphysiological, as it's not possible for BEE to be larger than TEE. Where data for BEE and PAL were missing, BEE and TEE were estimated using the Schofield equations[8] for the purpose of data screening.

The SAS code for calculating BMR according to Schofield equations is as follows:

```
If <Age<3 & Sex="M" then BMR_Mjd_Schofield = 0.0007*Weight
+ 6.349*Height/100 - 2.584;
if 3<=Age<10 & Sex="M" then BMR_Mjd_Schofield =
0.082*Weight + 0.545*Height/100 + 1.736;
if 10<=Age<18 & Sex="M" then BMR_Mjd_Schofield =
0.068*Weight + 0.574*Height/100 + 2.157;
if 18<=Age<30 & Sex="M" then BMR_Mjd_Schofield =
0.063*Weight - 0.042*Height/100 + 2.953;
if 30<=Age<60 & Sex="M" then BMR_Mjd_Schofield =
0.048*Weight - 0.011*Height/100 + 3.670;
if 60<=Age & Sex="M" then BMR_Mjd_Schofield = 0.038*Weight
+ 4.068*Height/100 - 3.491;

if <Age<3 & Sex="F" then BMR_Mjd_Schofield = 0.068*Weight +
4.281*Height/100 - 1.730;
if 3<=Age<10 & Sex="F" then BMR_Mjd_Schofield = 0.071*Weight
+ 0.677*Height/100 + 1.553;
if 10<=Age<18 & Sex="F" then BMR_Mjd_Schofield =
0.035*Weight + 1.948*Height/100 + 0.837;
if 18<=Age<30 & Sex="F" then BMR_Mjd_Schofield =
0.057*Weight + 1.184*Height/100 + 0.411;
if 30<=Age<60 & Sex="F" then BMR_Mjd_Schofield =
0.034*Weight + 0.006*Height/100 + 3.530;
if 60<=Age & Sex="F" then BMR_Mjd_Schofield = 0.033*Weight
+ 1.917*Height/100 + 0.074;

*Convert to kcal from MJ (BMR_kcal_Schofield);
BMR_kcal_Schofield = (BMR_Mjd_Schofield*1000)/4.184;

*Calculate PAL_est=TEE_kcal/BMR_kcal_Schofield;
PAL_est=TEE/BMR_kcal_Schofield;
label PAL_est= 'PAL estimated from BMR Schofield, in kcal/day';
```

[8] Schofield, W. N. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 39(Suppl 1):5-41. PMID: 4044297.

The following decision criteria were used to screen high or low values of PAL:

> For infants 0 to 11.9 months and children 1 to 3 years:
> If PAL (observed) was < 1 or > 2.5, then that child was removed from the database.
> If PAL was unobserved but PAL estimated from Schofield was < 1 or > 2.5, then that child was removed from the database.
> For children (4+) & adults:
> If observed PAL > 2.5, then that person was removed from the database.
> If observed PAL < 1, then PAL was made missing, and it was filled with multiple imputation (MI).
> If PAL was not observed, but PAL estimated from Schofield was > 2.5, then that person was removed from the database.
> If PAL was not observed, but PAL estimated from Schofield is < 1, the person remained in the database and PAL was left missing to be imputed (and truncated at 1 during imputation).

Note that while BEE and PAL estimates from Schofield were not used in TEE models, they were retained in the data set during multiple imputation as a "proxy" (or "auxiliary variables") that correlated with the variable to be imputed, which improves the precision of estimates.[9,10]

TABLE 5 Sample Sizes for Final Analysis Data Set, after Exclusions, by Data Source

Data source	*N*
IAEA	5717
IOM	2283
CNRC	220
SOLNAS	380
Combined data for analysis	8600

[9] Ejima, K., R. Zoh, C. Tekwe, D. Allison, and A. Brown. 2020. What proportion of planned missing data is allowed for unbiased estimates of the association between energy intake and body weight using multiple imputation? *Curr Dev Nutr* 4(Suppl 2):1167. doi: 10.1093/cdn/nzaa056_014. PMCID: PMC7258036.

[10] Cornish, R. P., J. Macleod, J. R. Carpenter, et al. 2017. Multiple imputation using linked proxy outcome data resulted in important bias reduction and efficiency gains: a simulation study. *Emerg Themes Epidemiol* 14(14). https://doi.org/10.1186/s12982-017-0068-0.

Based on the above, two analysis-ready data files were created:

1. one including the 8,722 participants for preliminary descriptive statistics and visualizations before PAL exclusions ("ALLDATA"), and
2. one including the 8,600 for final analysis ("ALLDATA_clean").

7. STATISTICAL METHODS

7.1 Multiple Imputation

PAL is a predictor in the TEE equations but was missing for 54.2% of the data (4,662 out of 8,600). Others in the field have estimated PAL using BEE (or actually, BMR) as estimated by equations such as Schofield (1985)[11] based on age, height, and weight. However, Dr. David Allison and the IU team preferred to use multiple imputation (MI) to estimate a variety of possible values of PAL using the information available in the other variables and maintaining the variability of the true data.

Note that PAL estimates from Schofield were retained in the data set during multiple imputation as a "proxy" (or "auxiliary variables") that correlated with the variable to be imputed, which improved the precision of estimates.[12,13,14]

The SAS procedure 'Proc MI' was used for imputation with Markov Chain Monte Carlo (MCMC) methods with multiple chains, using 20 imputations.

```
Proc MI data=df nimpute=pctmissing(min=5 max=20) out=outmi
seed=5849975;
    mcmc chain=multiple;
```

The combined clean data set (n = 8,600), including all ages and weights and pregnant and lactating women, was entered into the procedure with

[11] Ejima, K., R. Zoh, C. Tekwe, D. Allison, and A. Brown. 2020. What proportion of planned missing data is allowed for unbiased estimates of the association between energy intake and body weight using multiple imputation? *Curr Dev Nutr* 4(Suppl 2):1167. doi: 10.1093/cdn/nzaa056_014. PMCID: PMC7258036.

[12] Schofield, W. N. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* 39(Suppl 1):5-41.

[13] Cornish, R. P., J. Macleod, J. R. Carpenter et al. 2017. Multiple imputation using linked proxy outcome data resulted in important bias reduction and efficiency gains: a simulation study. *Emerg Themes Epidemiol* 14(4).

[14] Li, P., and E. A. Stuart. 2019. Best (but oft-forgotten) practices: Missing data methods in randomized controlled nutrition trials. *Am J Clin Nutr* 109(3):504-508. doi: 10.1093/ajcn/nqy271. PMID: 30793174; PMCID: PMC6408317. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6408317/.

all variables in the data set. All missing data for all variables in the data set were simultaneously imputed (e.g. PAL, FM, FFM) providing 20 versions of a complete data set.

PAL data were then evaluated again in the imputed data for unrealistic values, where PAL values < 1.0 (unphysiological) were truncated (Winsorized) at 1.0, and observations with values > 2.5 (unsustainable) were removed from that version of imputed data before analysis. Because there were 20 imputed data sets, these values were only removed in that specific imputation, and that person would remain in the other imputations where the values remained < 2.5.

7.2 Statistical Modeling

TEE models were fit separately for each strata:

- Infant/Toddler Boys (0–2.99 years old),
- Infant/Toddler Girls (0–2.99 years old),
- Child/Teen Boys (3.0–18.99 years old),
- Child/Teen Girls (3.0–18.99 years old),
- Men (19 and over),
- Women (19 and over),
- Pregnant Women

Within each stratum, the linear models were fit separately on each version of the imputed data set, obtaining the relevant regression equations in each iteration.

TEE is estimated as a function of a person's age, height and weight, and PAL, as a categorical measure "PALCAT": Sedentary/Inactive, Low Active, Active, Very Active as described above based on PAL (=TEE/BEE). Interaction terms are used to fit separate slopes for the effect of height and weight within each PALCAT.

$$\text{TEE} = \text{Intercept} + \text{Age (years)} + \text{Height (cm)} + \text{Weight (kg)} + \text{PALCAT} + \text{PALCAT} \times \text{Weight} + \text{PALCAT} \times \text{Height}$$

Because the raw parameter estimates for the model with interactions are not easily interpretable to a non-statistical audience, the IU team used 'estimate' statements in SAS[15,16] to calculate the estimates (and Standard Errors) for slopes of weight and height within each PALCAT.

[15] SAS Institute Inc. 2013. SAS/STAT 13.1 User's Guide. Cary, NC: SAS Institute Inc., page 3459. https://support.sas.com/documentation/onlinedoc/stat/131/glm.pdf

[16] Introduction to SAS. UCLA: Statistical Consulting Group, from https://stats.oarc.ucla.edu/sas/faq/how-do-i-write-an-estimate-statement-in-proc-glm/

The SAS code is pasted here, where &agecat. is a macro variable representing each age/sex strata. Also note that when reading the code below, the levels of PALCAT occur in alphabetical order in SAS (Active, Low Active, Sedentary, Very Active).

```
proc glm data=df&agecat.;
   by _imputation_;
   class PALCAT;
   model TEE = Age PALCAT Weight Height PALCAT*Weight
PALCAT*Height /solution;

   estimate 'Sedentary: Intercept' Intercept 1 PALCAT 0 0 1 0;
   estimate 'Sedentary: Age' Age 1;
   estimate 'Sedentary: Weight' Weight 1 PALCAT*Weight 0 0 1 0;
   estimate 'Sedentary: Height' Height 1 PALCAT*Height 0 0 1 0;

   estimate 'Low Active: Intercept' Intercept 1 PALCAT 0 1 0 0;
   estimate 'Low Active: Age' Age 1;
   estimate 'Low Active: Weight' Weight 1 PALCAT*Weight 0 1 0 0;
   estimate 'Low Active: Height' Height 1 PALCAT*Height 0 1 0 0;

   estimate 'Active: Intercept' Intercept 1 PALCAT 1 0 0 0;
   estimate 'Active: Age' Age 1;
   estimate 'Active: Weight' Weight 1 PALCAT*Weight 1 0 0 0;
   estimate 'Active: Height' Height 1 PALCAT*Height 1 0 0 0;

   estimate 'Very Active: Intercept' Intercept 1 PALCAT 0 0 0 1;
   estimate 'Very Active: Age' Age 1;
   estimate 'Very Active: Weight' Weight 1 PALCAT*Weight 0 0 0 1;
   estimate 'Very Active: Height' Height 1 PALCAT*Height 0 0 0 1;

  ods output Estimates=Est_&agecat. ParameterEstimates=Par_&ag
  ecat.;
  output out=newdf&agecat. p=predicted UCL=UCL LCL=LCL
  STDI=STDI;
run;
quit;
```

Coefficients obtained from the 'estimate' statements can then be presented more simply, to display an equation within each PAL category as:

$$TEE = Intercept + A \times Age\ (years) + B \times Height\ (cm) + C \times Weight\ (kg)$$

where 'A', 'B', and 'C' are the model-based coefficients for slopes of Age, Height, and Weight, respectively, for each PAL category.

Parameter estimates are then pooled across the 20 imputations using 'proc mianalyze' in SAS to provide final parameter estimates and standard errors.

SAS code is pasted here, where &agecat. is a macro variable representing each age/sex strata.

```
proc mianalyze data=Est_&agecat.;
   by Parameter;
   modeleffects Estimate ;
   stderr StdErr;
   ods output ParameterEstimates=Pooled_&agecat.;
run;
```

Children 0 to < 3 years old did not have separate models by PAL category; all data were pooled.

Analysis of pregnancy data included longitudinal data for women by trimester. Non-pregnant and non-lactating (NPNL) were included, coded as weeks=0 for analysis. Linear mixed models were performed with Proc Mixed in SAS using a repeated statement to account for the correlation of data over time within women. A variable was also added to the model for weeks of pregnancy.

7.3 Model Performance and Evaluation

Model performance is calculated as:

- R^2
- Adjusted R^2
- Shrunken R^2 (Browne formula)[17]
- Pearson r correlation
- MAPE (Mean Absolute Percentage Error)
- MAE (Mean Absolute Error)
- Mean squared error (MSE)
- Root mean squared error (RMSE)

using the following equations[18]:

[17] Yin, P., and X. Fan. 2001. Estimating R2 shrinkage in multiple regression: A comparison of different analytical methods. *J Experiment Educ* 69(2), 203–224. http://www.jstor.org/stable/20152659.

[18] Tibshirani, R., T. Hastie, G. James, and D. Witten. 2021. *An introduction to statistical learning: With applications in R.* United States: Springer US.

Let $y_1,\ldots,y_n$ be the observed values and $\hat{y}_1,\ldots,\hat{y}_n$ be the predicted values; let the mean of the observed values be $\bar{y}=1/n\sum y_i$; the mean of the predicted values be $\bar{\hat{y}}=1/n\sum\hat{y}_1$; the residual sum of square be $SS_{res}=\sum\left(\hat{y}_i-\hat{y}_i\right)^2$ and the total sum of squares be $SS_{tot}=\sum\left(y_i-\bar{y}\right)$. Finally, let k be the number of predictors in the model. Then,

$$R^2=1-\frac{SS_{res}}{SS_{tot}},$$

$$R^2_{adj}=1-\frac{n-1}{n-k-1}\left(1-R^2\right),$$

$$R^2_{shr}=\frac{\left(n-k-3\right)\left(R^2_{adj}\right)^2+R^2_{adj}}{\left(n-2k-2\right)R^2_{adj}+12},$$

$$r=\frac{\sum\left(y_i=\bar{y}\right)\left(\hat{y}_i-\bar{\hat{y}}\right)}{\sqrt{\sum\left(y_{i-}\bar{y}\right)^2\sum\left(\hat{y}_i-\bar{\hat{y}}\right)^2}},$$

$$MSE=\frac{1}{n}\sum_{i=1\ldots n}\left(y_i-\hat{y}_i\right)^2,$$

$$RMSE=\sqrt{MSE},$$

$$MAE=\frac{1}{n}\sum_{i=1\ldots n}\left|y_i-\hat{y}_i\right|^2,$$

$$MAPE=100\%\cdot\frac{1}{n}\sum_{i=1\ldots n}\frac{\left|y_i-\hat{y}_i\right|}{\left|y_i\right|}.$$

These are calculated in *R* code as follows, where 'TEE' is the true observed data (y_i), and 'TEE_pred.o' is the predicted value for TEE ($\hat{y}_i$). In the code below, the 'o' in TEE_pred.o is for the overweight/obese model, and the same is done for each BMI classification.

```
SSR = sum((TEE- TEE_pred.o)^2),
SST = sum((TEE- mean(TEE))^2),
R2= 1 - SSR/SST,
R2adj = 1 - ((1-R2) *(n-1)/(n-12-1)), #p=12, number of
        predictors
R2shr = ((n-12-3) *(R2adj)^2 + R2adj) /(  (n-2*12-2)*R2adj
        +12), #p=12
r = cor(TEE, TEE_pred.o, method="pearson"),
```

continued

```
MSE = SSR/n,
RMSE = sqrt(MSE),
MAE = sum(abs(TEE - TEE_pred.o))/n)
'MAPE (%)' = sum(abs((TEE-TEE_pred.o)/TEE))/n*100,
```

Note that both the RMSE and MAE are in the same units as the original TEE (kcal/day).

7.4 Model Validation

An out-of-sample model validation was performed on an external data set provided by WG1 ("Data extraction combined FINAL 081122"), which contained summary data (Means and SD) of DLW studies extracted from the literature and not in the combined DLW database.

Parameter estimates from the TEE equations developed on the main data set were used to calculate the predicted values of TEE on the external data, and those predicted values were compared to the observed (Mean) TEE values in the external validation data using the same measures described above, such as the *R*-squared and Pearson correlation of observed vs predicted values, as a measure of model fit and performance.

8. RESULTS

All statistical output was stored as HTML (.html) files created in R markdown (.Rmd). Additionally, to include results in the NASEM online appendix, the html output was also converted to PDF (.pdf) format.

Four pieces of output (each in html and pdf) are:

1. "DRI-energy-data-prep-and-prelim-stats"
2. "DRI-energy-clean-analysis"
3. "DRI-energy-MI-glm"
4. "Performance-Report"

Key findings are presented below.

8.1 Descriptive Statistics and Plots

Summary tables and descriptive plots are provided in:

(1) "DRI-energy-data-prep-and-prelim-stats" for all eligible data before excluding or truncating based on PAL < 1 or > 2.5 (as described in section 6.3) (n = 8,722), and

(2) "DRI-energy-clean-analysis" from final data for analysis (n = 8,600)

TABLE 6 Sample Sizes for Final Analysis Data Set, by Data Source and Age Group (Appendix P §2.1)

	CNRC	IAEA	IOM	SOLNAS	TOTAL
Infants	0	378	177	0	555
Children	0	432	689	0	1121
Teenagers	0	425	279	0	704
Adults	0	4309	767	380	5456
Preg/Lac/NPNL[19]	220	173	371	0	764
TOTAL	220	5717	2283	380	8600

Detailed descriptive statistics for the 8,600 observations included are presented in Appendix P, Section (§)3.

The non-linear relationship of TEE over age is shown in Figures 1 and 2 below (as well as in Appendix P §4).

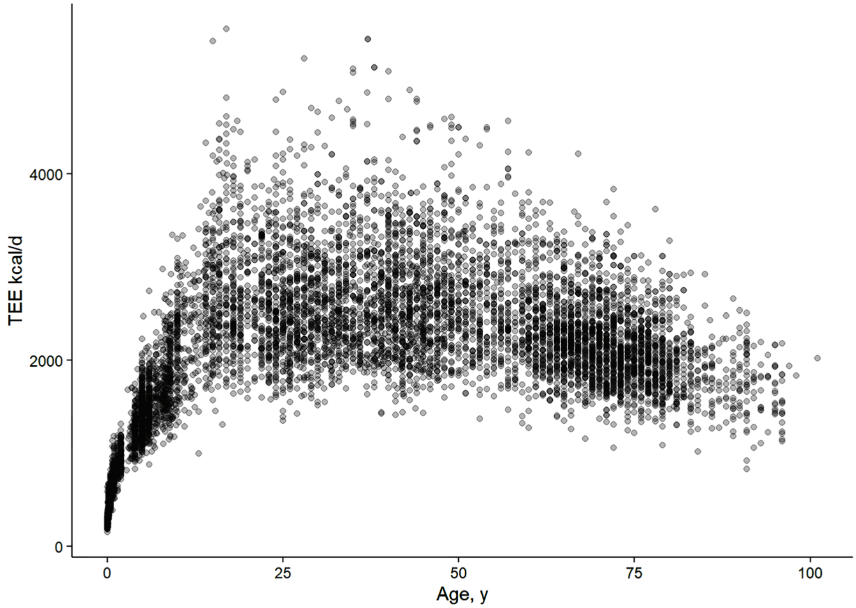

FIGURE 1 The relationship of TEE vs Age (Appendix P §4.18.5)

[19] NPNL is non-pregnant non-lactating but were women included in the studies of pregnant or lactating.

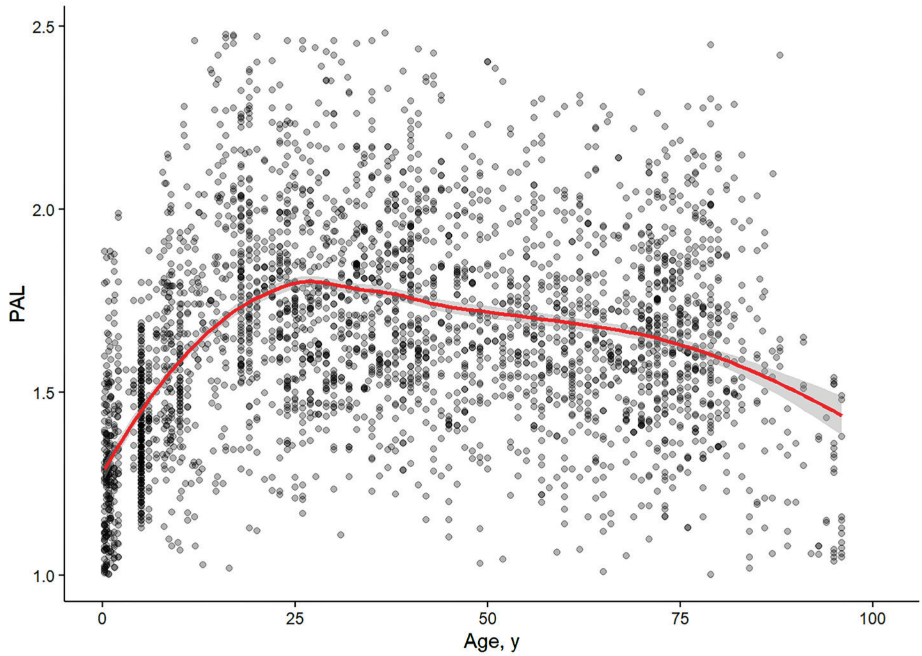

FIGURE 2 The relationship of PAL vs Age (Appendix P §4.11.5)

8.2 PAL Percentiles

PAL percentiles calculated from the imputed data were used to inform the quartiles by age group to use in classifying PAL levels. Bold numbers in Table 7 below were used to define the new age-dependent PAL categories as described above (Appendix Q §2.1).

TABLE 7 PAL Percentiles from Imputed Data by Age Categories (Appendix Q §2.1.1)

Percentile	-å/÷66 v k : 42-	0å5÷66 v k: 6/3	6å. 5÷66 v k: 4-1	. 6å4- ÷66 v k: 1/66	4. (v k : . /5.	I ^`q^qkd k : /-0	Mbdk^kq k: 10.			
10%	1.00	1.20	1.34	1.39	1.31	1.34	1.30			
25%	**1.11**	**1.31**	**1.50**	**1.53**	1.46	1.50	1.46			
50%	**1.27**	**1.44**	**1.66**	**1.68**	**1.62**	**1.69**	**1.60**			
75%	**1.44**	**1.59**	**1.85**	**1.85**	**1.79**	**1.83**	**1.77**			
90%	1.61	1.75	2.04	2.03	1.95	2.05	1.97			
Percentile	0–6 mo k = 443	7–11 mo k = 112	1–3 y k = 243	4–8 y k = 878	9–13 y k = 304	14–18 y k = 403	19–30 y k = 1,417	31–50 y k = 1,994	51–70 y k = 1,519	≥ 71 y k = 1,281
10%	1.00	1.08	1.06	1.20	1.29	1.40	1.35	1.39	1.39	1.31
25%	1.07	1.19	1.17	1.32	**1.44**	**1.56**	1.50	1.53	1.52	1.46
50%	1.23	1.31	1.33	1.44	**1.59**	**1.73**	1.67	1.69	1.67	1.62
75%	1.40	1.47	1.49	1.60	**1.77**	**1.92**	1.85	1.86	1.82	1.79
90%	1.58	1.65	1.64	1.76	1.92	2.11	2.05	2.03	1.99	1.95

The distribution of PAL within age group is shown in Figure 3 (and Appendix Q §2.2).

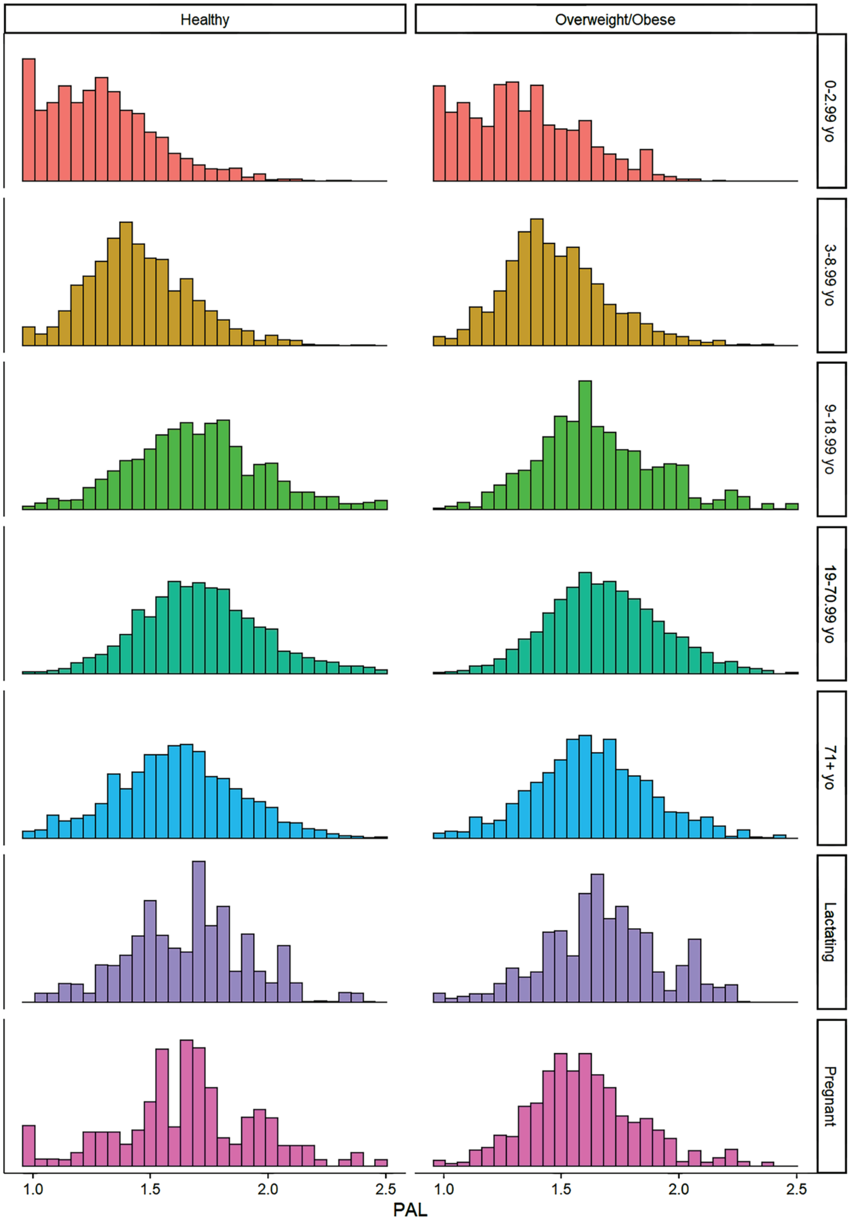

FIGURE 3 Histograms of PAL by age group (Appendix Q §2.2)

8.3 TEE Equations

Final TEE models with coefficients for age, height, and weight by PAL category (Sedentary, Low Active, Active, Very Active) and age/sex strata are as follows (from Appendix Q §11):

Women, 19 years and above

- Sedentary: 584.90 – 7.01 Age (y) + 5.72 Height (cm) + 11.71 Weight (kg)
- Low Active: 575.77 – 7.01 Age (y) + 6.60 Height (cm) + 12.14 Weight (kg)
- Active: 710.25 – 7.01 Age (y) + 6.54 Height (cm) + 12.34 Weight (kg)
- Very Active: 511.83 – 7.01 Age (y) + 9.07 Height (cm) + 12.56 Weight (kg)

Men, 19 years and above

- Sedentary: 753.07 – 10.83 Age (y) + 6.50 Height (cm) + 14.10 Weight (kg)
- Low Active: 581.47 – 10.83 Age (y) + 8.30 Height (cm) + 14.94 Weight (kg)
- Active: 1004.82 – 10.83 Age (y) + 6.52 Height (cm) + 15.91 Weight (kg)
- Very Active: –517.88 – 10.83 Age (y) + 15.61 Height (cm) + 19.11 Weight (kg)

Girls, 3 to 18 years old

- Sedentary: 55.59 – 22.25 Age (y) + 8.43 Height (cm) + 17.07 Weight (kg)
- Low Active: –297.54 – 22.25 Age (y) + 12.77 Height (cm) + 14.73 Weight (kg)
- Active: –189.55 – 22.25 Age (y) + 11.74 Height (cm) + 18.34 Weight (kg)
- Very Active: –709.59 – 22.25 Age (y) + 18.22 Height (cm) + 14.25 Weight (kg)

Boys, 3 to 18 years old

- Sedentary: –447.51 + 3.68 Age (y) + 13.01 Height (cm) + 13.15 Weight (kg)
- Low Active: 19.12 + 3.68 Age (y) + 8.62 Height (cm) + 20.28 Weight (kg)
- Active: –388.19 + 3.68 Age (y) + 12.66 Height (cm) + 20.46 Weight (kg)
- Very Active: –671.75 + 3.68 Age (y) + 15.38 Height (cm) + 23.25 Weight (kg)

Girls, 0 to 2 years old

- –69.15 + 80.00 Age (y) + 2.65 Height (cm) + 54.15 Weight (kg)

Boys, 0–2 years old

- –716.45 – 1.00 Age (y) + 17.82 Height (cm) + 15.06 Weight (kg)

Pregnant women

- Sedentary: 1131.20 – 2.04 Age (y) + 0.34 Height (cm) + 12.15 Weight (kg) + 9.16 Weeks pregnant
- Low Active: 693.35 – 2.04 Age (y) + 5.73 Height (cm) + 10.20 Weight (kg) + 9.16 Weeks pregnant
- Active: –223.84 – 2.04 Age (y) + 13.23 Height (cm) + 8.15 Weight (kg) + 9.16 Weeks pregnant
- Very Active: –779.72 – 2.04 Age (y) + 18.45 Height (cm) + 8.73 Weight (kg) + 9.16 Weeks pregnant

Model coefficients are shown here for the primary models, including all BMI levels. Coefficients for sensitivity analyses removing high and low BMI or separated for "healthy" or "overweight/obese" are included for each strata in Appendix Q §3 (Women 19+) through §9 (Pregnant).

8.4 Model Performance

Model performance and validation is outlined in the "Performance-Report." A summary of model fit measures for the primary models including all BMI levels are listed here in Table 8 (Appendix R §1.8).

TABLE 8 Model Fit for Each Age/Sex Stratum (Appendix R §1.8)

Strata	n	R^2	R^2 adj	R^2 shr	r	MSE	RMSE	MAPE (%)	MAE
Adult Women 19+	1342	0.71	0.70	0.70	0.84	60393.43	245.75	8.67	190.89
Adult Men 19+	1016	0.73	0.73	0.73	0.86	114615.05	338.55	9.35	265.54
Girls 3–18	477	0.84	0.84	0.83	0.92	56049.24	236.75	8.19	165.44
Boys 3–18	250	0.92	0.92	0.92	0.97	66831.33	258.52	7.11	163.25
Girls 0–2	432	0.83	0.83	0.83	0.91	9059.24	95.18	12.80	73.51
Boys 0–2	317	0.83	0.83	0.83	0.91	10732.61	103.60	13.56	79.47
Pregnancy	413	0.63	0.62	0.61	0.80	79769.92	282.44	8.80	222.10

R^2 adj = adjusted R^2, R^2 shr = shrunken R^2, as described in methods above, along with MSE, MAPE, and MAE.

Table 9 shows the mean and standard deviation of the difference in observed TEE – predicted TEE (i.e., the error) from the primary models in each stratum (Appendix R §1.10). The mean of the error is useful as a measure of bias, indicating a general tendency for whether the true values tend to be above or below the predicted values. Bland-Altman plots[20] are displayed in Appendix R §1.10 to visually display the differences in observed – predicted values

TABLE 9 Mean (Bias) and Standard Deviation of the Difference in Observed TEE – Predicted TEE, by Stratum (Appendix R §1.10)

Strata	n	Mean	Std Dev.
Adult Women 19+	1342	0.611	245.842
Adult Men 19+	1016	29.387	337.437
Girls 3–18	477	11.452	236.718
Boys 3–18	250	43.162	255.400
Girls 0–2	432	0.510	95.289
Boys 0–2	317	0.059	103.762
Pregnancy	413	39.593	279.986

Prediction Error was calculated to show the precision of estimates if a new person's TEE was predicted based on their age, height, weight, and PAL. We first calculated the predicted TEE and Standard Error (SE) based on a person at an average level of age, height and weight, with an "Active" PAL level within each strata (Table 10A, Appendix Q §10.1) and then also for someone above average (2 standard deviations above the mean) (Table 10B, Appendix Q §10.2).

TABLE 10A Prediction Error for Estimating a New Person's TEE at Average Levels of Age, Height, and Weight, with "Active" PAL level (Appendix Q §10.1)

Strata	Age	Height	Weight	Weeks preg	Predicted TEE	SE of the predicted value
Adult Women 19+	53.87	162.34	71.87	—	2,280.94	240.93
Adult Men 19+	50.25	175.92	83.10	—	2,930.26	342.37
Girls 3–18	9.58	135.02	37.63	—	1,872.65	221.06
Boys 3–18	8.65	134.03	37.06	—	2,098.77	257.61

continued

[20] P. S. Myles, J. Cui, I. 2007. Using the Bland–Altman method to measure agreement with repeated measures, *BJA: Brit J Anaesthesia* 99(3):309–311. https://doi.org/10.1093/bja/aem214.

TABLE 10A Continued

Strata	Age	Height	Weight	Weeks preg	Predicted TEE	SE of the predicted value
Girls 0–2	0.72	68.31	7.81	—	592.58	95.87
Boys 0–2	0.69	68.46	8.03	—	623.81	104.42
Pregnant	29.40	164.13	74.89	19.86	2,679.76	302.35

TABLE 10B Prediction Error for Estimating a New Person's TEE at 2 SD above Average Levels of Age, Height, and Weight, with "Active" PAL level (Appendix Q §10.2)

Strata	Age	Height	Weight	Weeks preg	Predicted TEE	SE of the predicted value
Adult Women 19+	53.87	169.43	87.99	—	2,526.23	241.28
Adult Men 19+	50.25	183.46	99.55	—	3,241.22	343.32
Girls 3–18	9.58	157.71	57.12	—	2,496.52	223.35
Boys 3–18	8.65	161.26	58.34	—	2,878.92	262.99
Girls 0–2	0.72	78.81	10.36	—	758.52	96.96
Boys 0–2	0.69	79.06	10.76	—	853.83	105.88
Pregnant	29.40	170.72	95.07	19.86	2,931.34	306.19

8.5 External Validation

Model fit statistics were used to evaluate the out-of-sample data as described above. Tables 11A and 11B show the model fit from the predicted values after applying the TEE models to the study-level data extracted from the literature (Appendix R §4.2). The analyses were performed first for the studies with PAL available, with the second imputing PAL using Schofield equations based on the study averages for age, height, and weight.

TABLE 11A Model Fit from External Validation with Complete Data for PAL (Appendix R §4.2.1)

Strata	k	R^2	*r*	J PB	OJ PB	J >MB % &
Boy	8	0.90	0.96	95,651.47	309.28	7.90
Girl	7	0.82	0.97	56,812.37	238.35	10.38
Man	14	0.85	0.93	45,699.40	213.77	6.00
Woman	25	0.85	0.94	44,940.87	211.99	6.83

TABLE 11B Model Fit from External Validation with PAL Imputed for Schofield Equations (Appendix R §4.2.2)

Strata	k	R^2	*r*	J PB	OJ PB	J >MB % &
Boy	21	0.92	0.96	61,755.86	248.51	7.72
Girl	20	0.87	0.97	35,342.89	188.00	8.01
Man	32	0.82	0.92	49,684.74	222.90	5.57
Woman	71	0.82	0.93	28,833.66	169.80	5.46

9. APPENDICES[21]

Supplemental online files

Appendix	Description
Appendix N	DLW Data Codebook
Appendix O	Data Preparation and Preliminary Descriptive Statistics
Appendix P	Clean Analysis
Appendix Q	Multiple Imputation GLM Results
Appendix R	Performance Report
Appendix S	List of IAEA Studies with Inclusion/Exclusion

continued

[21] All appendixes to this IU report are provided in Supplemental Appendixes N through W and are available at: https://nap.nationalacademies.org/catalog/26818.

Addendum to Appendix G
Details of Redefining of the TEE Model

As described in Chapter 5, a general model of TEE used age, height, weight, and PAL category as predictors and also included interactions of the PAL category with height and weight. The model performed to predict TEE used the following format:

$$TEE = Intercept_0 + A \times Age\ (years) + B_0 \times Height\ (cm) + C_0 \times Weight\ (kg) + D_i \times PALCAT_i + I_{BDi} \times PALCAT_i \times Height\ (cm) + I_{CDi} \times PALCAT_i \times Weight\ (kg) + error$$

where $PALCAT_i$ represents 3 indicator variables for PAL category (Active, Low Active, Inactive) that are coded as 0 or 1; 'A', 'B_0', 'C_0', and 'D_i' are the model coefficients for the main effects of age, height, weight and the 3 PAL categories, respectively; and 'I_{BDi}' and 'I_{BCi}' are the model coefficients for the interaction of the 3 PAL categories with height and weight, respectively. (The full model output including all the coefficients for interaction terms of height and weight by PAL category are provided in supplemental Appendix Q[1]). Moving the main effect of PAL category, and regrouping the terms by height and weight yields:

[1] Supplemental appendixes are available at: https://nap.nationalacademies.org/catalog/26818.

$$TEE = Intercept_0 + D \times PALCAT_i + A \times Age\ (years) + (B_0 + I_{BDi} \times PALCAT_i) \times Height\ (cm) + (C_0 + I_{CDi} \times PALCAT_i) \times Weight\ (kg) + error$$

In this model, the intercept represents the mean TEE level when Age, Weight, and Height are all 0. Obviously, this does not occur, and therefore it is not meaningful by itself, and, could even be negative. The coefficients for Age, Height, and Weight may be thought of as slopes—i.e., positive slopes represent increasing energy expenditure and negative slopes decreasing energy expenditure for a change in the corresponding variable holding the other values constant (e.g., for adult females, there is on average a decrease of 10.83 kcal/d for each 1-year increase in age, for women of the same weight, height, and physical activity level). The interaction terms allow the height and weight effects to differ for each PAL category, and the interaction coefficient (I_{BDi} for height, I_{CDi} for weight) represents the deviation from the referent group (Very Active).

Recognizing that $PALCAT_i$ represents 3 indicator (0 or 1) variables (i=Active, Low Active, Inactive) and that Very Active is the reference category (all 3 are 0), we can write the predicted value for each category by substituting the 0 or 1 for $PALCAT_i$. For example, for the Active group:

$$TEE_{Active} = (Intercept_0 + D_{Active} \times 1) + (D_{Inactive} \times 0) + (D_{LActive} \times 0) + A \times Age\ (years) + (B_0 + I_{BDActive} \times 1) \times Height\ (cm) + (B_0 + I_{BDInactive} \times 0) \times Height\ (cm) + (B_0 + I_{BDLActive} \times 0) \times Height\ (cm) + (C_0 + I_{CDActive} \times 1) \times Weight\ (kg) + (C_0 + I_{CDInactive} \times 0) \times Weight\ (kg) + (C_0 + I_{CDLActive} \times 0) \times Weight\ (kg),$$

which, after multiplying by the indicator values of 0 or 1, simplifies to:

$$TEE_{Active} = Intercept_{Active} + A \times Age\ (years) + (B_0 + I_{BDActive}) \times Height\ (cm) + (C_0 + I_{CDActive}) \times Weight\ (kg),$$

where $Intercept_{Active} = Intercept_0 + D_{Active}$.

This equation can be written simply as:

$$TEE_i = Intercept + A \times Age\ (years) + B \times Height\ (cm) + C \times Weight\ (kg)$$

where 'A' is the same as above, 'Intercept' represents the sum of the intercept in the full model ($Intercept_0$) and the 'D_i' coefficient for the indicator for the PAL category, 'B' is the sum of the 'B_0' coefficient from the full model and the 'I_{BDi}' coefficient from the full model for the corresponding

PAL category, and 'C' is the sum of the 'C_0' coefficient from the full model and the 'I_{CDi}' coefficient from the full model for the corresponding PAL category. All PAL levels could be predicted in the same manner. For the special case of the referent group (Very Active), all indicator variables are 0, so the prediction is simply:

$$TEE_{VActive} = Intercept_0 + A \times Age\ (years) + B_0 \times Height\ (cm) + C_0 \times Weight\ (kg)$$

which also simplifies to the equation directly above.

DIFFERENCE IN EQUATIONS COMPARED TO THE 2005 EER:

For the 2005 EER, the following prediction of TEE was used:

$$TEE = Intercept + A \times Age\ (years) + PA \times (B \times Height\ (cm) + C \times Weight\ (kg)),$$

where 'A', 'B', and 'C' are the coefficients for age, height, and weight respectively, and 'PA' is a coefficient for each PAL category that is multiplied by both height and weight. By substitution of the four coefficients for PA, this prediction could also be written separately for each PAL category, as above. Also, similar to the TEE prediction equation above, the coefficient for Age remains constant for each PAL category. However, in contrast to the TEE prediction equation above, the intercept also remains constant, and, although the coefficients for Height and Weight vary by PAL category, they are mutltiplied by the same PA coefficient, whereas in the equation above, the parameters represent a deviation from the overall slope, which is not restricted to be the same for height and weight. A comparison of the EER values from 2005 and 2023 is presented in Chapter 7.

Appendix H

Characteristics of the DLW Database

Box H-1
Data Sets and Variables Requested from SOLNAS

Data Sets Requested: biea_lad1.sas7bdat; csea_lad1.sas7bdatt; dlwa_lad1.sas7bdat; vsea_lad1.sas7bdat; vtea_lad1.sas7bdat
Variables requested:
Age (CSEA3)
Participant Sex (BIEA1)
Starting Weight (VSEA3B)
Height (VSEA3A)
BMI (DLWA34)
Ethnicity (all will be labeled as Hispanic)
Year of data collection (all should be coded as 2011-12)
Country (will be labeled as US)
Calorimetry body weight (CSEA2)
Final weight (VTEA2A)
kO (DLWA29)
kH (DLWA28)
18O space (DLWA25)
2H space (DLWA23)
VCO2 (DLWA32)
RQ mean, SD, CV (CSEA4C1, C2, C3)
RQ source (will be labeled as indirect calorimetry for all)
Lean body mass (DLWA35)
Body fat (DLWA36)
EE mean, SD, CV (CSEA4D1, D2, D3)

continued

Box H-1 Continued

BEE method (calorimetry)
TEE0-12 days (DLWA33)
FQ (DLWA13)
FQ source (DLWA19)

Data Sets Requested: Physical Activity data sets: pa_derv_solnas_lad1.sas7bddat
Variables requested: all the physical activity derived variables for those included in SOLNAS

Data Sets Requested: Smoking variables from tbea_lad1.sas7bdat
Variables requested: TBEA1-smoke at least 100 cigs in lifetime; TBEA3-present smoking status

Data Sets Requested: Health status variables from mhea_lad1.sas7bdat
Variables Requested: MHEA1-HBP/hypertension-self reported; MHEA16-diabetes-self reported.

SOURCE: Data from SOLNAS are publicly available on the National Heart, Lung, and Blood Institute's (NHLBI's) Biological Specimen and Data Repository Information Coordinating Center (BIOLINCC) site: https://biolincc.nhlbi.nih.gov/home/.

TABLE H-1 Characteristics of All Participants, 0–100+ Years, Included in Combined Doubly Labeled Water (DLW) Database, Except Pregnant or Lactating Women

	Females (N = 5,025)	Males (N = 2,919)	Overall (N = 7,944)
Age (years)			
N	5,025	2,919	7,944
Mean (SD)	40.52 (27.16)	34.86 (26.36)	38.44 (27.01)
Median [Min, Max]	40.00 [0.03, 98.00]	33.00 [0.02, 101.00]	37.05 [0.02, 101.00]
Life Stage			
0–6 months	266 (5.29%)	203 (6.95%)	469 (5.90%)
7–11 months	69 (1.37%)	45 (1.54%)	114 (1.44%)
1–3 years	145 (2.89%)	105 (3.60%)	250 (3.15%)
4–8 years	495 (9.85%)	384 (13.2%)	879 (11.1%)
9–13 years	184 (3.66%)	120 (4.11%)	304 (3.83%)
14–18 years	259 (5.15%)	158 (5.41%)	417 (5.25%)
19–30 years	633 (12.6%)	368 (12.6%)	1,001 (12.6%)
31–50 years	987 (19.6%)	703 (24.1%)	1,690 (21.3%)
51–70 years	1,079 (21.5%)	448 (15.3%)	1,527 (19.2%)
≥71 years	908 (18.1%)	385 (13.2%)	1,293 (16.3%)

TABLE H-1 Continued

	Females (N = 5,025)	Males (N = 2,919)	Overall (N = 7,944)
Sex			
Cbj ^ib	5,025 (100%)	0 (0%)	5,025 (63.3%)
J ^ib	0 (0%)	2919 (100%)	2919 (36.7%)
Ethnicity			
> cof`^k > j bof`^k	605 (12.08%)	235 (8.056%)	840 (10.526%)
> pf^k	103 (2.05%)	96 (3.29%)	199 (2.51%)
T efcp	2,240 (44.6%)	1,282 (43.9%)	3,522 (44.3%)
E fpm^kf`	350 (6.97%)	201 (6.89%)	551 (6.94%)
L qebo	44 (0.876%)	29 (0.993%)	73 (0.919%)
Rkhkl t k l oa ^q^ kl q ^s ^fi^_ib	1,683 (33.5%)	1,076 (36.9%)	2,759 (34.7%)
Height (cm)			
N	5,013	2,901	7,914
J b^k %PA&	148.73 (29.99)	154.27 (38.27)	150.76 (33.37)
J ba f^k X fk) J ^uZ	160.00 [46.40, 196.00]	172.00 [47.30, 204.70]	162.50 [46.40, 204.70]
Weight (kg)			
N	5,022	2,913	7,935
J b^k %PA&	59.55 (26.51)	63.83 (32.32)	61.12 (28.85)
J ba f^k X fk) J ^uZ	63.30 [2.36, 164.55]	72.95 [2.70, 215.70]	66.00 [2.36, 215.70]
Fat-Free Mass (kg)			
N	3,833	2,143	5,976
J b^k %PA&	38.79 (12.48)	48.32 (20.46)	42.21 (16.46)
J ba f^k X fk) J ^uZ	40.91 [1.80, 95.74]	54.61 [2.28, 97.81]	43.41 [1.80, 97.81]
Fat Mass (kg)			
N	3,829	2,139	5,968
J b^k %PA&	26.09 (13.62)	19.92 (12.56)	23.88 (13.58)
J ba f^k X fk) J ^uZ	25.33 [0.12, 92.14]	19.72 [0.07, 90.27]	23.39 [0.07, 92.14]
Fat Mass %			
N	3,829	2,139	5,968
J b^k %PA&	37.84 (8.85)	27.67 (8.32)	34.20 (9.94)
J ba f^k X fk) J ^uZ	38.67 [3.69, 70.08]	27.88 [2.06, 56.19]	34.53 [2.06, 70.08]
Body Mass Index			
N	5,010	2,897	7,907
J b^k %PA&	24.73 (6.78)	23.84 (6.10)	24.40 (6.55)

continued

TABLE H-1 Continued

	Females (*N* = 5,025)	Males (*N* = 2,919)	Overall (*N* = 7,944)
J□ ba f^k□X fk)□ J ^uZ	24.04 [10.77, 57.87]	23.86 [10.89, 61.70]	23.96 [10.77, 61.70]
BMI Category			
<□.5-2	986 (19.7%)	681 (23.5%)	1,667 (21.1%)
≥□□5-2□^ka□9□/2	1,824 (36.4%)	998 (34.4%)	2,822 (35.7%)
≥□/2□^ka□9□0-	1,208 (24.1%)	808 (27.9%)	2,016 (25.5%)
≥□0-□^ka□9□02	605 (12.1%)	283 (9.77%)	888 (11.2%)
≥□02□^ka□9□1-	250 (4.99%)	92 (3.18%)	342 (4.33%)
≥□1-	137 (2.73%)	35 (1.21%)	172 (2.18%)
BMI Percentile			
N	1,406	997	2,403
J b^k□%PA&	59.13 (27.02)	58.88 (28.92)	59.03 (27.82)
J□ ba f^k□X fk)□ J ^uZ	60.40 [0.73, 99.38]	60.61 [0.09, 99.90]	60.43 [0.09, 99.90]
BMI Percentile Category			
9□2cp	20 (1.42%)	23 (2.31%)	43 (1.79%)
2cp□d□52cp	1,067 (75.9%)	716 (71.8%)	1,783 (74.2%)
52cp□d□62cp	161 (11.5%)	109 (10.9%)	270 (11.2%)
; □62cp	158 (11.2%)	149 (14.9%)	307 (12.8%)
Total Energy Expenditure (kcal/d)			
N	5,018	2,914	7,932
J b^k□%PA&	1,992.37 (648.51)	2,453.55 (1,001.50)	2,161.79 (826.96)
J□ ba f^k□X fk)□ J ^uZ	2,067.66 [145.48, 4,873.09]	2,605.24 [151.10, 8,190.40]	2,180.67 [145.48, 8,190.40]
Basal Metabolic Rate Observed (kcal/d)			
N	2,031	1,412	3,443
J b^k□%PA&	1,236.78 (323.07)	1,519.16 (438.80)	1,352.59 (399.73)
J□ ba f^k□X fk)□ J ^uZ	1,260.00 [263.00, 2,576.00]	1,570.27 [286.00, 3,035.00]	1,353.00 [263.00, 3,035.00]

TABLE H-1 Continued

	Females (*N* = 5,025)	Males (*N* = 2,919)	Overall (*N* = 7,944)
Physical Activity Level Observed			
N	2,027	1,411	3,438
Mean (SD)	1.65 (0.31)	1.69 (0.34)	1.66 (0.32)
Median [Min, Max]	1.63 [0.92, 3.35]	1.65 [0.83, 4.03]	1.64 [0.83, 4.03]
Physical Activity Level Category Observed			
PAL < 1.0	9 (0.444%)	7 (0.496%)	16 (0.465%)
Inactive	540 (26.6%)	323 (22.9%)	863 (25.1%)
Low Active	515 (25.4%)	357 (25.3%)	872 (25.4%)
Active	442 (21.8%)	305 (21.6%)	747 (21.7%)
Very Active	498 (24.6%)	386 (27.4%)	884 (25.7%)
PAL > 2.5	23 (1.13%)	33 (2.34%)	56 (1.63%)
Basal Metabolic Rate Predicted (kcal/d)			
N	5,010	2,895	7,905
Mean (SD)	1,259.80 (341.86)	1,509.07 (524.23)	1,351.09 (434.87)
Median [Min, Max]	1,332.52 [99.67, 2,829.45]	1,676.26 [100.69, 3,346.80]	1,384.63 [99.67, 3,346.80]
Missing	15 (0.3%)	24 (0.8%)	39 (0.5%)
Physical Activity Level Observed + Predicted (TEE/BMR)			
N	5,007	2,896	7,903
Mean (SD)	1.59 (0.27)	1.63 (0.31)	1.60 (0.29)
Median [Min, Max]	1.57 [0.65, 3.35]	1.60 [0.72, 4.35]	1.58 [0.65, 4.35]
Physical Activity Level Category Observed + Predicted			
PAL < 1.0	27 (0.540%)	20 (0.693%)	47 (0.596%)
Inactive	1,767 (35.3%)	815 (28.2%)	2,582 (32.7%)
Low Active	1,358 (27.2%)	744 (25.8%)	2,102 (26.7%)
Active	971 (19.4%)	594 (20.6%)	1,565 (19.8%)

continued

TABLE H-1 Continued

	Females (*N* = 5,025)	Males (*N* = 2,919)	Overall (*N* = 7,944)
Sbov> `qfsb	853 (17.1%)	681 (23.6%)	1,534 (19.4%)
M I ; /2	23 (0.460%)	34 (1.18%)	57 (0.723%)

NOTE: BMI = body mass index; BMR = basal metabolic rate; cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; m = meter; max = maximum; min = minimum; PAL = physical activity level; SD = standard deviation; TEE = total energy expenditure.

TABLE H-2 Characteristics of Infants, 0–11 Months, Included in Combined DLW Database

	Females (*N* = 335)	Males (*N* = 248)	Overall (*N* = 583)
Age (years)			
N	335	248	583
J b^k %PA&	0.39 (0.25)	0.38 (0.26)	0.39 (0.25)
J ba f^k X fk) J ^uZ	0.27 [0.03, 1.00]	0.26 [0.02, 0.99]	0.27 [0.02, 1.00]
Life Stage			
-å3 j 1 kqp	266 (79.4%)	203 (81.9%)	469 (80.4%)
4å. . j 1 kqp	69 (20.6%)	45 (18.1%)	114 (19.6%)
Sex			
Cbj ^ibp	335 (100%)	0 (0%)	335 (57.5%)
J ^ibp	0 (0%)	248 (100%)	248 (42.5%)
Ethnicity			
> of` ^k > j bof` ^k	0 (0%)	1 (0.403%)	1 (0.172%)
> pf^k	2 (0.597%)	1 (0.403%)	3 (0.515%)
T efqb	111 (33.1%)	72 (29.0%)	183 (31.4%)
E fpm^kf`	16 (4.78%)	13 (5.24%)	29 (4.97%)
L qebo	9 (2.69%)	14 (5.65%)	23 (3.95%)
Rkhkl t k 1 o a ^q^ kl q ^s ^fi^_ib	197 (58.8%)	147 (59.3%)	344 (59.0%)
Length (cm)			
N	334	248	582
J b^k %PA&	63.08 (6.50)	63.44 (6.81)	63.24 (6.63)
J ba f^k X fk) J ^uZ	62.38 [46.40, 80.00]	63.00 [47.30, 78.80]	62.70 [46.40, 80.00]
Weight (kg)			
N	335	248	583
J b^k %PA&	6.62 (1.77)	6.84 (1.87)	6.72 (1.81)
J ba f^k X fk) J ^uZ	6.46 [2.36, 11.30]	6.80 [2.70, 12.60]	6.60 [2.36, 12.60]

TABLE H-2 Continued

	Females (*N* = 335)	Males (*N* = 248)	Overall (*N* = 583)
Fat-Free Mass (kg)			
K	217	176	393
J b^k%PA&	4.52 (1.07)	4.84 (1.18)	4.67 (1.13)
J ba f^k X fk) J ^uZ	4.38 [1.80, 7.94]	4.77 [2.28, 8.74]	4.54 [1.80, 8.74]
Fat Mass (kg)			
N	216	176	392
J b^k%PA&	1.67 (0.77)	1.64 (0.83)	1.66 (0.80)
J ba f^k X fk) J ^uZ	1.58 [0.12, 4.28]	1.54 [0.07, 3.86]	1.56 [0.07, 4.28]
Fat Mass %			
N	216	176	392
J b^k%PA&	25.98 (6.76)	23.98 (7.49)	25.08 (7.15)
J ba f^k X fk) J ^uZ	26.72 [3.69, 50.61]	24.40 [2.06, 41.65]	25.65 [2.06, 50.61]
Weight-for-Length Percentile			
N	334	248	582
J b^k%PA&	51.10 (26.97)	50.93 (29.02)	51.03 (27.84)
J ba f^k X fk) J ^uZ	51.76 [0.73, 99.38]	50.03 [0.09, 99.90]	51.04 [0.09, 99.90]
Weight-for-Length Percentile Category			
9 0œa	5 (1.50%)	8 (3.23%)	13 (2.23%)
0œa q 64œ	322 (96.4%)	233 (94.0%)	555 (95.4%)
; 64œ	7 (2.10%)	7 (2.82%)	14 (2.41%)
Total Energy Expenditure (kcal/d)			
N	335	248	583
J b^k%PA&	481.03 (159.86)	510.77 (190.95)	493.68 (174.23)
J ba f^k X fk) J ^uZ	466.06 [145.48, 961.00]	493.61 [151.10, 1,187.32]	475.81 [145.48, 1,187.32]
Basal Metabolic Rate Observed (kcal/d)			
K	109	66	175
J b^k%PA&	443.51 (91.47)	472.56 (95.08)	454.47 (93.65)
J ba f^k X fk) J ^uZ	435.00 [263.00, 649.00]	472.00 [286.00, 649.00]	447.00 [263.00, 649.00]

continued

TABLE H-2 Continued

	Females (*N* = 335)	Males (*N* = 248)	Overall (*N* = 583)
Physical Activity Level Observed			
N	109	66	175
J b^k %PA&	1.27 (0.20)	1.27 (0.22)	1.27 (0.21)
J baf^k X fk) J ^uZ	1.26 [0.95, 1.88]	1.28 [0.83, 1.80]	1.27 [0.83, 1.88]
Physical Activity Level Category Observed			
M I 9 .	4 (3.67%)	6 (9.09%)	10 (5.71%)
Fk^`qfsb	66 (60.6%)	32 (48.5%)	98 (56.0%)
I l t > `qfsb	21 (19.3%)	13 (19.7%)	34 (19.4%)
> `qfsb	11 (10.1%)	9 (13.6%)	20 (11.4%)
Sbov > `qfsb	7 (6.42%)	6 (9.09%)	13 (7.43%)
M I ; /-2	0 (0%)	0 (0%)	0 (0%)
Basal Metabolic Rate (kcal/d) Predicted			
N	334	248	582
J b^k %PA&	339.70 (94.17)	346.25 (103.69)	342.49 (98.31)
J baf^k X fk) J ^uZ	326.67 [99.67, 577.34]	339.55 [100.69, 579.94]	333.19 [99.67, 579.94]
Physical Activity Level Observed + Predicted			
N	334	248	582
J b^k %PA&	1.37 (0.26)	1.42 (0.30)	1.39 (0.28)
J baf^k X fk) J ^uZ	1.35 [0.65, 2.41]	1.38 [0.77, 2.40]	1.36 [0.65, 2.41]
Physical Activity Level Category Observed + Predicted			
M I 9 .	14 (4.19%)	13 (5.24%)	27 (4.64%)
Fk^`qfsb	135 (40.4%)	79 (31.9%)	214 (36.8%)
I l t > `qfsb	74 (22.2%)	49 (19.8%)	123 (21.1%)
> `qfsb	55 (16.5%)	39 (15.7%)	94 (16.2%)
Sbov > `qfsb	56 (16.8%)	68 (27.4%)	124 (21.3%)
M I ; /-2	0 (0%)	0 (0%)	0 (0%)

NOTE: cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; m = meter; max = maximum; min = minimum; PAL = physical activity level; SD = standard deviation.

TABLE H-3 Characteristics of Children, 1–8 Years, Included in Combined DLW Database

	Females (*N* = 640)	Males (*N* = 489)	Overall (*N* = 1,129)
Age (years)			
N	640	489	1,129
Mean (SD)	5.23 (2.28)	4.78 (1.81)	5.03 (2.10)
Median [Min, Max]	5.00 [1.00, 8.90]	5.00 [1.00, 8.50]	5.00 [1.00, 8.90]
Life Stage			
1–3 years	145 (22.7%)	105 (21.5%)	250 (22.1%)
4–8 years	495 (77.3%)	384 (78.5%)	879 (77.9%)
Sex			
Females	640 (100%)	0 (0%)	640 (56.7%)
Males	0 (0%)	489 (100%)	489 (43.3%)
Ethnicity			
African American	15 (2.34%)	32 (6.54%)	47 (4.16%)
Asian	4 (0.625%)	0 (0%)	4 (0.354%)
Whites	100 (15.6%)	88 (18.0%)	188 (16.7%)
Hispanic	11 (1.72%)	23 (4.70%)	34 (3.01%)
Other	1 (0.156%)	2 (0.409%)	3 (0.266%)
Unknown or data not available	509 (79.5%)	344 (70.3%)	853 (75.6%)
Height (cm)			
N	633	475	1,108
Mean (SD)	110.86 (17.15)	109.30 (15.09)	110.19 (16.31)
Median [Min, Max]	113.40 [71.00, 155.00]	112.00 [72.00, 153.00]	113.00 [71.00, 155.00]
Weight (kg)			
N	640	489	1,129
Mean (SD)	21.47 (8.41)	20.90 (7.46)	21.22 (8.01)
Median [Min, Max]	20.50 [8.20, 66.00]	20.00 [8.40, 68.40]	20.27 [8.20, 68.40]
Fat-Free Mass (kg)			
N	208	223	431
Mean (SD)	13.54 (3.92)	14.83 (4.27)	14.20 (4.15)
Median [Min, Max]	13.42 [5.40, 31.43]	14.65 [6.47, 29.17]	14.09 [5.40, 31.43]
Fat Mass (kg)			
N	208	223	431
Mean (SD)	5.59 (3.47)	5.31 (3.37)	5.44 (3.42)
Median [Min, Max]	4.73 [1.01, 24.57]	4.32 [1.22, 20.33]	4.62 [1.01, 24.57]

continued

TABLE H-3 Continued

	Females (*N* = 640)	Males (*N* = 489)	Overall (*N* = 1,129)
Fat Mass %			
N	208	223	431
J b^k%PA&	27.76 (6.77)	25.12 (6.84)	26.40 (6.92)
J baf^kX fk) J ^uZ	26.47 [10.48, 58.34]	23.95 [10.93, 50.31]	25.24 [10.48, 58.34]
Body Mass Index Percentile			
N	633	475	1,108
J b^k%PA&	60.17 (27.37)	60.56 (29.03)	60.33 (28.08)
J baf^kX fk) J ^uZ	61.45 [2.79, 98.45]	62.14 [2.88, 97.40]	61.56 [2.79, 98.45]
BMI Percentile Category			
9 2ce	9 (1.42%)	8 (1.68%)	17 (1.53%)
2ce dl 52ce	462 (73.0%)	329 (69.3%)	791 (71.4%)
52ce dl 62ce	75 (11.8%)	53 (11.2%)	128 (11.6%)
; 62ce	87 (13.7%)	85 (17.9%)	172 (15.5%)
Total Energy Expenditure (kcal/d)			
N	640	489	1,129
J b^k%PA&	1,359.80 (377.65)	1,424.46 (372.36)	1,387.80 (376.57)
J baf^kX fk) J ^uZ	1,343.11 [517.00, 2,699.00]	1,421.00 [560.14, 2,975.00]	1,376.49 [517.00, 2,975.00]
Basal Metabolic Rate Observed (kcal/d)			
N	300	194	494
J b^k%PA&	934.61 (203.47)	1,001.27 (208.88)	960.79 (207.97)
J baf^kX fk) J ^uZ	969.50 [456.00, 1,490.00]	1,030.00 [530.00, 1,470.00]	985.00 [456.00, 1,490.00]
Physical Activity Level Observed			
N	300	194	494
J b^k%PA&	1.45 (0.24)	1.40 (0.17)	1.43 (0.21)
J baf^kX fk) J ^uZ	1.43 [0.92, 2.15]	1.38 [0.99, 1.91]	1.41 [0.92, 2.15]

TABLE H-3 Continued

	Females (*N* = 640)	Males (*N* = 489)	Overall (*N* = 1,129)
Physical Activity Level Category Observed			
M> I 9 .	5 (1.67%)	1 (0.515%)	6 (1.21%)
Fk^`qfsb	74 (24.7%)	54 (27.8%)	128 (25.9%)
I l t > `qfsb	74 (24.7%)	71 (36.6%)	145 (29.4%)
> `qfsb	72 (24.0%)	43 (22.2%)	115 (23.3%)
Sbov > `qfsb	75 (25.0%)	25 (12.9%)	100 (20.2%)
M> I ; /2	0 (0%)	0 (0%)	0 (0%)
Basal Metabolic Rate Predicted (kcal/d)			
N	633	475	1,108
J b^k %PA&	898.15 (191.71)	945.12 (193.07)	918.28 (193.61)
J ba f^k X fk) J ^uZ	905.05 [456.00, 1,733.87]	947.55 [476.41, 1,954.74]	928.96 [456.00, 1,954.74]
Physical Activity Level Observed + Predicted			
N	635	477	1,112
J b^k %PA&	1.47 (0.22)	1.46 (0.20)	1.46 (0.21)
J ba f^k X fk) J ^uZ	1.45 [0.92, 2.43]	1.44 [0.99, 2.60]	1.44 [0.92, 2.60]
Physical Activity Level Category Observed + Predicted			
M> I 9 .	5 (0.787%)	2 (0.419%)	7 (0.629%)
Fk^`qfsb	135 (21.3%)	106 (22.2%)	241 (21.7%)
I l t > `qfsb	163 (25.7%)	133 (27.9%)	296 (26.6%)
> `qfsb	175 (27.6%)	125 (26.2%)	300 (27.0%)
Sbov > `qfsb	157 (24.7%)	110 (23.1%)	267 (24.0%)
M> I ; /2	0 (0%)	1 (0.210%)	1 (0.0899%)

NOTE: cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; max = maximum; min = minimum; PAL = physical activity level; SD = standard deviation.

TABLE H-4 Characteristics of Children and Teens, 9–18 Years, Included in Combined DLW Database

	Females (N = 443)	Males (N = 278)	Overall (N = 721)
Age (years)			
N	443	278	721
J b^k□%PA&	13.86 (3.05)	13.56 (3.12)	13.75 (3.08)
J□ba f^k□X fk)□ J ^uZ	14.60 [9.00, 18.80]	14.00 [9.00, 18.90]	14.20 [9.00, 18.90]
Life Stage			
6å. 0□vb^op	184 (41.5%)	120 (43.2%)	304 (42.2%)
. 1å. 5□vb^op	259 (58.5%)	158 (56.8%)	417 (57.8%)
Sex			
Cbj ^ibp	443 (100%)	0 (0%)	443 (61.4%)
J ^ibp	0 (0%)	278 (100%)	278 (38.6%)
Ethnicity			
>coof`^k□ >j bof`^k	26 (5.871%)	17 (6.12%)	43 (5.966%)
>pf^k	2 (0.451%)	1 (0.360%)	3 (0.416%)
T efcp	149 (33.6%)	141 (50.7%)	290 (40.2%)
E fpm^kf`	0 (0%)	1 (0.360%)	1 (0.139%)
Lqebo	11 (2.48%)	4 (1.44%)	15 (2.08%)
R□khkl t k□ l o□a ^q^□kl q□ ^s ^fi^_ib	255 (57.6%)	114 (41.0%)	369 (51.2%)
Height (cm)			
N	439	274	713
J b^k□%PA&	156.63 (12.85)	163.78 (18.37)	159.38 (15.59)
J□ba f^k□X fk)□ J ^uZ	159.20 [116.00, 183.70]	168.90 [125.00, 201.00]	161.00 [116.00, 201.00]
Weight (kg)			
N	443	277	720
J b^k□%PA&	54.43 (16.50)	58.78 (17.66)	56.10 (17.07)
J□ba f^k□X fk)□ J ^uZ	54.25 [22.20, 133.20]	60.00 [23.50, 125.70]	56.30 [22.20, 133.20]
Fat-Free Mass (kg)			
N	238	201	439
J b^k□%PA&	39.78 (8.73)	47.81 (13.54)	43.46 (11.88)
J□ba f^k□X fk)□ J ^uZ	39.70 [14.65, 95.74]	49.62 [19.26, 73.58]	42.39 [14.65, 95.74]
Fat Mass (kg)			
N	238	201	439
J b^k□%PA&	20.57 (9.82)	14.89 (8.84)	17.97 (9.79)
J□ba f^k□X fk)□ J ^uZ	17.90 [6.05, 66.05]	12.94 [3.08, 54.33]	15.97 [3.08, 66.05]

TABLE H-4 Continued

	Females (*N* = 443)	Males (*N* = 278)	Overall (*N* = 721)
Fat Mass %			
N	238	201	439
J b^k %PA&	33.07 (7.45)	23.36 (9.53)	28.62 (9.75)
J ba f^k X J fk) J ^uZ	32.21 [8.03, 59.57]	21.10 [6.01, 53.92]	28.33 [6.01, 59.57]
Body Mass Index Percentile			
N	439	274	713
J b^k %PA&	63.75 (25.20)	63.17 (27.30)	63.53 (26.01)
J ba f^k X J fk) J ^uZ	66.28 [5.09, 97.60]	64.43 [3.95, 97.57]	65.28 [3.95, 97.60]
BMI Percentile Category			
9 2qe	0 (0%)	3 (1.09%)	3 (0.421%)
2qe ql 52qe	322 (73.3%)	191 (69.7%)	513 (71.9%)
52qe ql 62qe	59 (13.4%)	28 (10.2%)	87 (12.2%)
; 62qe	58 (13.2%)	52 (19.0%)	110 (15.4%)
Total Energy Expenditure (kcal/d)			
N	441	277	718
J b^k %PA&	2,300.37 (544.75)	2,891.46 (789.38)	2,528.41 (710.54)
J ba f^k X J fk) J ^uZ	2,274.19 [1,000.00, 4,873.09]	2,753.99 [1,178.00, 5,555.39]	2,413.88 [1,000.00, 5,555.39]
Basal Metabolic Rate Observed (kcal/d)			
N	262	107	369
J b^k %PA&	1,362.30 (233.26)	1,679.31 (378.90)	1,454.22 (317.31)
J ba f^k X J fk) J ^uZ	1,327.50 [881.00, 2,218.00]	1,610.00 [1,025.00, 3,010.00]	1,403.00 [881.00, 3,010.00]
Physical Activity Level Observed			
N	262	107	369
J b^k %PA&	1.75 (0.34)	1.81 (0.41)	1.77 (0.36)
J ba f^k X J fk) J ^uZ	1.71 [1.02, 2.82]	1.73 [1.03, 4.03]	1.72 [1.02, 4.03]

continued

TABLE H-4 Continued

	Females (*N* = 443)	Males (*N* = 278)	Overall (*N* = 721)
Physical Activity Level Category Observed			
PAL < 1.0	0 (0%)	0 (0%)	0 (0%)
Inactive	57 (21.8%)	11 (10.3%)	68 (18.4%)
Low Active	62 (23.7%)	25 (23.4%)	87 (23.6%)
Active	53 (20.2%)	32 (29.9%)	85 (23.0%)
Very Active	81 (30.9%)	33 (30.8%)	114 (30.9%)
PAL > 2.5	9 (3.44%)	6 (5.61%)	15 (4.07%)
Missing	181 (40.9%)	171 (61.5%)	352 (48.8%)
Basal Metabolic Rate (kcal/d) Predicted			
N	439	273	712
Mean (SD)	1,384.22 (185.29)	1,690.05 (302.00)	1,501.48 (279.62)
Median [Min, Max]	1,391.68 [942.38, 2,196.50]	1,717.34 [1,043.51, 2,815.00]	1,446.60 [942.38, 2,815.00]
Physical Activity Level Observed + Predicted			
N	439	275	714
Mean (SD)	1.67 (0.31)	1.71 (0.34)	1.69 (0.32)
Median [Min, Max]	1.64 [1.02, 2.82]	1.68 [1.02, 4.03]	1.65 [1.02, 4.03]
Physical Activity Level Observed + Predicted			
PAL < 1.0	0 (0%)	0 (0%)	0 (0%)
Inactive	141 (32.1%)	65 (23.8%)	206 (28.9%)
Low Active	106 (24.1%)	72 (26.4%)	178 (25.0%)
Active	90 (20.5%)	67 (24.5%)	157 (22.1%)
Very Active	93 (21.2%)	63 (23.1%)	156 (21.9%)
PAL > 2.5	9 (2.05%)	6 (2.20%)	15 (2.11%)

NOTE: cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; max = maximum; min = minimum; PAL = physical activity level; SD = standard deviation.

TABLE H-5 Characteristics of Adults, 19 Years and Older, Included in Combined DLW Database

	Females (*N* = 3,607)	Males (*N* = 1,904)	Overall (*N* = 5,511)
Age (years)			
N	3,607	1,904	5,511
J b^k %PA&	53.79 (19.79)	50.19 (19.35)	52.54 (19.71)
J ba f^k X fk) J ^uZ	56.00 [19.00, 98.00]	47.90 [19.00, 101.00]	52.00 [19.00, 101.00]
Life Stage			
. 6å0- vb^op	633 (17.5%)	368 (19.3%)	1,001 (18.2%)
0. å2- vb^op	987 (27.4%)	703 (36.9%)	1,690 (30.7%)
2. å4- vb^op	1,079 (29.9%)	448 (23.5%)	1,527 (27.7%)
; : 4. vb^op	908 (25.2%)	385 (20.2%)	1,293 (23.5%)
Sex			
Cbj ^ibp	3,607 (100%)	0 (0%)	3,607 (65.5%)
J ^ibp	0 (0%)	1,904 (100%)	1,904 (34.5%)
Race/Ethnicity			
> cof`^k >j bof`^k	564 (15.655%)	185 (9.713%)	749 (13.627%)
> pf^k	95 (2.63%)	94 (4.94%)	189 (3.43%)
T efcp	1,880 (52.1%)	981 (51.5%)	2,861 (51.9%)
E fpm^kf`	323 (8.95%)	164 (8.61%)	487 (8.84%)
L qebo	23 (0.638%)	9 (0.473%)	32 (0.581%)
R khkl t k l o a ^q^ kl q ^s ^fi^_ib	722 (20.0%)	471 (24.7%)	1,193 (21.6%)
Height (cm)			
N	3,607	1,904	5,511
J b^k %PA&	162.35 (7.09)	175.95 (7.60)	167.05 (9.73)
J ba f^k X fk) J ^uZ	162.50 [137.00, 196.00]	176.00 [147.00, 204.70]	166.00 [137.00, 204.70]
Weight (kg)			
K	3,604	1,899	5,503
J b^k %PA&	71.86 (16.12)	83.06 (16.44)	75.73 (17.08)
J ba f^k X fk) J ^uZ	69.00 [37.80, 164.55]	80.10 [37.20, 215.70]	73.68 [37.20, 215.70]
Fat-Free Mass (kg)			
N	3,170	1,543	4,713
J b^k %PA&	42.72 (6.62)	58.19 (8.92)	47.79 (10.40)
J ba f^k X fk) J ^uZ	41.99 [21.11, 81.31]	57.66 [28.87, 97.81]	45.52 [21.11, 97.81]

continued

TABLE H-5 Continued

	Females (*N* = 3,607)	Males (*N* = 1,904)	Overall (*N* = 5,511)
Fat Mass (kg)			
N	3,167	1,539	4,706
Mean (SD)	29.52 (11.57)	24.79 (10.55)	27.97 (11.46)
Median [Min, Max]	27.59 [3.61, 92.14]	23.62 [2.23, 90.27]	26.22 [2.23, 92.14]
Fat Mass %			
N	3,167	1,539	4,706
Mean (SD)	39.67 (7.94)	29.03 (8.04)	36.19 (9.41)
Median [Min, Max]	40.39 [6.55, 70.08]	29.48 [2.91, 56.19]	36.77 [2.91, 70.08]
Body Mass Index			
N	3,604	1,900	5,504
Mean (SD)	27.24 (5.88)	26.82 (4.85)	27.10 (5.55)
Median [Min, Max]	26.08 [14.69, 57.87]	25.99 [14.33, 61.70]	26.03 [14.33, 61.70]
BMI Category			
< 18.5	48 (1.33%)	20 (1.05%)	68 (1.24%)
≥ 18.5 and < 25	1,451 (40.3%)	716 (37.7%)	2,167 (39.4%)
≥ 25 and < 30	1,143 (31.7%)	770 (40.5%)	1,913 (34.8%)
≥ 30 and < 35	588 (16.3%)	275 (14.5%)	863 (15.7%)
≥ 35 and < 40	245 (6.80%)	84 (4.42%)	329 (5.98%)
≥ 40	129 (3.58%)	35 (1.84%)	164 (2.98%)
Total Energy Expenditure (kcal/d)			
N	3,602	1,900	5,502
Mean (SD)	2,207.62 (424.76)	2,908.15 (638.17)	2,449.53 (608.00)
Median [Min, Max]	2,169.83 [833.81, 4,450.48]	2,850.97 [1,181.61, 8,190.40]	2,343.21 [833.81, 8,190.40]
Basal Metabolic Rate Observed (kcal/d)			
N	1,360	1,045	2,405
Mean (SD)	1,342.84 (225.32)	1,665.00 (306.63)	1,482.82 (308.30)
Median [Min, Max]	1,330.00 [773.00, 2,576.00]	1,649.14 [884.08, 3,035.00]	1,446.00 [773.00, 3,035.00]

TABLE H-5 Continued

	Females (*N* = 3,607)	Males (*N* = 1,904)	Overall (*N* = 5,511)
Physical Activity Level Observed (TEE/BMR)			
N	1,356	1,044	2,400
J b^k %PA&	1.70 (0.28)	1.76 (0.31)	1.73 (0.30)
J ba f^k X fk) J ^uZ	1.68 [1.00, 3.35]	1.72 [1.02, 3.22]	1.70 [1.00, 3.35]
Physical Activity Level Category Observed			
M I 9	0 (0%)	0 (0%)	0 (0%)
Fk^`qfs b	343 (25.3%)	226 (21.6%)	569 (23.7%)
I l t > `qfs b	358 (26.4%)	248 (23.8%)	606 (25.3%)
> `qfs b	306 (22.6%)	221 (21.2%)	527 (22.0%)
Sbov > `qfs b	335 (24.7%)	322 (30.8%)	657 (27.4%)
M I ; /2	14 (1.03%)	27 (2.59%)	41 (1.71%)
Basal Metabolic Rate Predicted (kcal/d)			
N	3,604	1,899	5,503
J b^k %PA&	1,393.44 (172.71)	1,775.97 (250.99)	1,525.45 (272.66)
J ba f^k X fk) J ^uZ	1,374.35 [1,000.33, 2,829.45]	1,769.52 [1,069.83, 3,346.80]	1,455.59 [1,000.33, 3,346.80]
Physical Activity Level Observed + Predicted			
N	3,599	1,896	5,495
J b^k %PA&	1.62 (0.26)	1.69 (0.31)	1.65 (0.28)
J ba f^k X fk) J ^uZ	1.60 [0.70, 3.35]	1.65 [0.72, 4.35]	1.61 [0.70, 4.35]
J fppfkd	8 (0.2%)	8 (0.4%)	16 (0.3%)
Physical Activity Level Category Observed + Predicted			
M I 9	8 (0.223%)	5 (0.265%)	13 (0.237%)
Fk^`qfs b	1,356 (37.8%)	565 (29.9%)	1,921 (35.0%)
I l t > `qfs b	1,015 (28.3%)	490 (25.9%)	1,505 (27.5%)
> `qfs b	651 (18.1%)	363 (19.2%)	1,014 (18.5%)
Sbov > `qfs b	547 (15.2%)	440 (23.3%)	987 (18.0%)
M I ; /2	14 (0.390%)	27 (1.43%)	41 (0.748%)

NOTE: BMI = body mass index; BMR = basal metabolic rate; cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; m = meter; max = maximum; min = minimum; PAL = physical activity level; SD = standard deviation; TEE = total energy expenditure.

TABLE H-6 Characteristics of Pregnant Women Included in Combined DLW Database

	1st Trimester (*N* = 31)	2nd Trimester (*N* = 201)	3rd Trimester (*N* = 206)	NPNL (*N* = 133)	Overall (*N* = 571)
Sex					
Cbj ^ibp	31 (100%)	201 (100%)	206 (100%)	133 (100%)	571 (100%)
Pregnant					
Vbp	31 (100%)	201 (100%)	206 (100%)	0 (0%)	438 (76.7%)
K1	0 (0%)	0 (0%)	0 (0%)	133 (100%)	133 (23.3%)
Lactating					
K1	31 (100%)	201 (100%)	206 (100%)	133 (100%)	571 (100%)
Pregnancy Stage					
. pqQofj bpcpo	31 (100%)	0 (0%)	0 (0%)	0 (0%)	31 (5.43%)
/ka Qofj bpcpo	0 (0%)	201 (100%)	0 (0%)	0 (0%)	201 (35.2%)
0oa Qofj bpcpo	0 (0%)	0 (0%)	206 (100%)	0 (0%)	206 (36.1%)
NPNL	0 (0%)	0 (0%)	0 (0%)	133 (100%)	133 (23.3%)
Weeks					
N	31	201	206	133	571
J b^k %PA&	9.29 (2.61)	19.14 (4.30)	34.83 (2.29)	0.00 (0.00)	19.81 (13.71)
J baf^k X fk) J ^uZ	9.00 [6.00, 12.00]	18.00 [14.50, 27.00]	36.00 [30.00, 38.14]	0.00 [0.00, 0.00]	20.86 [0.00, 38.14]
Age					
N	31	201	206	133	571
J b^k %PA&	28.83 (3.22)	29.06 (4.43)	29.28 (4.23)	30.24 (4.09)	29.40 (4.24)
J baf^k X fk) J ^uZ	29.00 [21.00, 33.00]	29.00 [18.00, 41.00]	29.00 [18.00, 41.00]	30.00 [21.00, 41.00]	29.00 [18.00, 41.00]

Life Stage					
. 6å0- vb^op	19 (61.3%)	120 (59.7%)	124 (60.2%)	71 (53.4%)	334 (58.5%)
0. å2- vb^op	12 (38.7%)	79 (39.3%)	81 (39.3%)	62 (46.6%)	234 (41.0%)
. 1å. 5 vb^op	0 (0%)	2 (0.995%)	1 (0.485%)	0 (0%)	3 (0.525%)
Height (cm)					
N	30	200	205	133	568
J b^k %PA&	164.13 (7.38)	5,991.15 (7,797.23)	4,752.45 (7,328.27)	6,988.55 (8,039.83)	5,469.86 (7,617.11)
J baf^k X fk) J ^uZ	164.00 [155.00, 180.00]	170.00 [142.10, 17,820.00]	168.00 [142.10, 17,830.00]	172.00 [149.81, 17,680.00]	168.85 [142.10, 17,830.00]
Weight (kg)					
N	30	200	205	133	568
J b^k %PA&	63.23 (8.61)	78.31 (21.19)	82.75 (20.48)	60.95 (10.66)	75.05 (20.44)
J baf^k X fk) J ^uZ	62.21 [50.57, 77.70]	74.50 [48.60, 164.60]	76.20 [55.40, 170.70]	59.30 [40.10, 102.20]	69.90 [40.10, 170.70]
Fat-Free Mass (kg)					
N	0	70	60	0	130
J b^k %PA&	NA (NA)	54.34 (8.11)	62.25 (9.69)	NA (NA)	57.99 (9.68)
J baf^k X fk) J ^uZ	NA [NA, NA]	52.98 [40.74, 77.54]	61.61 [45.09, 89.83]	NA [NA, NA]	57.53 [40.74, 89.83]
Fat Mass (kg)					
N	0	70	60	0	130
J b^k %PA&	NA (NA)	45.60 (12.07)	44.54 (10.65)	NA (NA)	45.11 (11.41)
J baf^k X fk) J ^uZ	NA [NA, NA]	42.33 [29.22, 87.27]	42.93 [28.20, 82.56]	NA [NA, NA]	42.68 [28.20, 87.27]

continued

TABLE H-6 Continued

	1st Trimester (N = 31)	2nd Trimester (N = 201)	3rd Trimester (N = 206)	NPNL (N = 133)	Overall (N = 571)
Fat Mass %					
N	0	70	60	0	130
J b^k %PA&	NA (NA)	45.17 (4.62)	41.45 (5.04)	NA (NA)	43.45 (5.15)
J baf^k X fk) J ^uZ	NA [NA, NA]	45.09 [36.14, 58.25]	40.92 [32.85, 54.82]	NA [NA, NA]	43.18 [32.85, 58.25]
Body Mass Index					
N	30	200	205	133	568
J b^k %PA&	23.48 (2.98)	29.05 (7.39)	30.65 (7.31)	22.52 (3.59)	27.81 (7.27)
J baf^k X fk) J ^uZ	22.96 [18.80, 29.97]	27.11 [18.75, 56.31]	28.12 [20.79, 57.63]	21.53 [17.43, 35.61]	25.63 [17.43, 57.63]
BMI Category					
9 .5-2	0 (0%)	0 (0%)	0 (0%)	11 (8.27%)	11 (1.94%)
≥ .5-2 ^ka 9 /2	22 (73.3%)	79 (39.5%)	59 (28.8%)	93 (69.9%)	253 (44.5%)
≥ /2 ^ka 9 0-	8 (26.7%)	37 (18.5%)	55 (26.8%)	24 (18.0%)	124 (21.8%)
≥ 0- ^ka 9 02	0 (0%)	43 (21.5%)	36 (17.6%)	3 (2.26%)	82 (14.4%)
≥ 02 ^ka 9 1-	0 (0%)	24 (12.0%)	29 (14.1%)	2 (1.50%)	55 (9.68%)
≥ 1-	0 (0%)	17 (8.50%)	26 (12.7%)	0 (0%)	43 (7.57%)

Total Energy Expenditure (kcal/d)					
N	31	201	206	133	571
J b^k %PA&	2,289.11 (311.55)	2,553.66 (559.56)	2,779.89 (558.64)	2,478.24 (444.24)	2,603.35 (542.28)
J baf^k X fk) J ^uZ	2,323.00 [1,628.11, 2,904.88]	2,544.22 [1,149.38, 7,543.25]	2,736.52 [1,526.29, 4,880.26]	2,431.17 [1,277.96, 3,937.13]	2,574.00 [1,149.38, 7,543.25]
Basal Metabolic Rate Observed					
N	31	131	141	130	433
J b^k %PA&	1,454.83 (173.23)	1,464.87 (197.34)	1,710.76 (213.91)	1,363.62 (163.61)	1,513.82 (238.85)
J baf^k X fk) J ^uZ	1,447.00 [1,046.00, 1,833.41]	1,435.55 [848.47, 1,975.71]	1,698.14 [1,040.39, 2,392.59]	1,362.21 [859.50, 1,843.11]	1,483.99 [848.47, 2,392.59]
Physical Activity Level Observed (TEE/BMR)					
N	30	56	85	73	244
J b^k %PA&	1.60 (0.17)	1.67 (0.40)	1.66 (0.35)	1.79 (0.34)	1.69 (0.35)
J baf^k X fk) J ^uZ	1.64 [1.19, 1.92]	1.61 [1.05, 4.00]	1.60 [1.12, 2.91]	1.75 [1.17, 2.58]	1.64 [1.05, 4.00]

continued

TABLE H-6 Continued

	1st Trimester (*N* = 31)	2nd Trimester (*N* = 201)	3rd Trimester (*N* = 206)	NPNL (*N* = 133)	Overall (*N* = 571)
Physical Activity Level Category Observed					
M>I 9	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Hk^`qfsb	10 (33.3%)	15 (26.8%)	35 (41.2%)	20 (27.4%)	80 (32.8%)
I l t >`qfsb	11 (36.7%)	24 (42.9%)	17 (20.0%)	14 (19.2%)	66 (27.0%)
>`qfsb	7 (23.3%)	6 (10.7%)	13 (15.3%)	14 (19.2%)	40 (16.4%)
Sbov>`qfsb	2 (6.67%)	9 (16.1%)	17 (20.0%)	23 (31.5%)	51 (20.9%)
M>I ; /2	0 (0%)	2 (3.57%)	3 (3.53%)	2 (2.74%)	7 (2.87%)
Basal Metabolic Rate Predicted (kcal/d)					
N	30	200	205	133	568
J b^k %PA&	1,396.41 (108.07)	8,693.97 (16,536.12)	6,785.12 (14,459.64)	9,304.05 (17,303.25)	7,762.45 (15,628.54)
J ba f^k X fk) J ^uZ	1,398.26 [1,255.12, 1,642.45]	1,656.29 [1,204.61, 51,563.86]	1,651.91 [1,300.54, 51,717.50]	1,473.57 [1,141.94, 51,034.18]	1,588.13 [1,141.94, 51,717.50]
Physical Activity Level Observed + Predicted					
N	31	201	206	133	571
J b^k %PA&	1.58 (0.20)	1.32 (0.62)	1.42 (0.56)	1.44 (0.70)	1.40 (0.61)
J ba f^k X fk) J ^uZ	1.64 [0.99, 1.92]	1.49 [0.04, 4.00]	1.53 [0.04, 2.91]	1.60 [0.04, 2.58]	1.53 [0.04, 4.00]

Physical Activity Level Category Observed + Predicted					
M>I □9 □	1 (3.23%)	34 (17.0%)	26 (12.6%)	24 (18.0%)	85 (14.9%)
Ek^`qfsb	10 (32.3%)	81 (40.5%)	77 (37.4%)	30 (22.6%)	198 (34.7%)
I l t □>`qfsb	11 (35.5%)	44 (22.0%)	51 (24.8%)	27 (20.3%)	133 (23.3%)
>`qfsb	7 (22.6%)	23 (11.5%)	23 (11.2%)	23 (17.3%)	76 (13.3%)
Sbov□>`qfsb	2 (6.45%)	16 (8.00%)	26 (12.6%)	27 (20.3%)	71 (12.5%)
M>I □; □/2	0 (0%)	2 (1.00%)	3 (1.46%)	2 (1.50%)	7 (1.23%)

NOTE: BMI = body mass index; BMR = basal metabolic rate; cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; m = meter; max = maximum; min = minimum; NPNL = nonpregnant nonlactating; PAL = physical activity level; SD = standard deviation; TEE = total energy expenditure.

TABLE H-7 Characteristics of Lactating Women Included in Combined DLW Database

	Lactating 1–3 mo (*N* = 93)	Lactating 4–6 mo (*N* = 114)	Overall (*N* = 207)
Sex			
Females	93 (100%)	114 (100%)	207 (100%)
Pregnant			
No	93 (100%)	114 (100%)	207 (100%)
Lactating			
Yes	93 (100%)	114 (100%)	207 (100%)
Lactation Stage			
Lactating 1–3 mo	93 (100%)	0 (0%)	93 (44.9%)
Lactating 4–6 mo	0 (0%)	114 (100%)	114 (55.1%)
Weeks			
N	93	114	207
Mean (SD)	9.24 (2.98)	24.85 (2.18)	17.83 (8.20)
Median [Min, Max]	8.70 [4.30, 13.00]	25.00 [19.00, 27.00]	20.60 [4.30, 27.00]
Age			
N	93	114	207
Mean (SD)	30.39 (3.90)	30.23 (4.12)	30.30 (4.01)
Median [Min, Max]	30.00 [21.00, 41.00]	30.00 [21.00, 41.00]	30.00 [21.00, 41.00]
Life Stage			
19–30 years	54 (58.1%)	59 (51.8%)	113 (54.6%)
31–50 years	39 (41.9%)	55 (48.2%)	94 (45.4%)
Height (cm)			
N	92	114	206
Mean (SD)	164.69 (6.07)	5,266.09 (7,547.46)	2,987.79 (6,153.29)
Median [Min, Max]	165.00 [149.81, 180.00]	168.85 [142.10, 17,570.00]	167.00 [142.10, 17,570.00]
Weight (kg)			
N	92	114	206
Mean (SD)	62.18 (9.86)	76.40 (22.70)	70.05 (19.43)
Median [Min, Max]	60.10 [45.50, 87.90]	69.86 [42.50, 139.20]	63.50 [42.50, 139.20]
Fat-Free Mass (kg)			
N	5	39	44
Mean (SD)	41.19 (3.34)	52.93 (7.57)	51.60 (8.12)
Median [Min, Max]	41.18 [36.36, 44.80]	51.86 [34.67, 73.00]	51.07 [34.67, 73.00]

TABLE H-7 Continued

	Lactating 1–3 mo (*N* = 93)	Lactating 4–6 mo (*N* = 114)	Overall (*N* = 207)
Fat Mass (kg)			
N	5	39	44
Mean (SD)	22.02 (13.64)	48.37 (12.43)	45.38 (15.02)
Median [Min, Max]	14.57 [14.10, 45.77]	47.96 [25.21, 77.43]	46.65 [14.10, 77.43]
Fat Mass %			
N	5	39	44
Mean (SD)	32.90 (11.96)	47.22 (6.17)	45.59 (8.25)
Median [Min, Max]	28.00 [23.94, 53.44]	46.61 [33.10, 62.23]	45.74 [23.94, 62.23]
Body Mass Index			
N	92	114	206
Mean (SD)	22.89 (3.18)	28.15 (8.15)	25.80 (6.93)
Median [Min, Max]	22.42 [18.21, 31.57]	25.85 [17.87, 49.25]	23.50 [17.87, 49.25]
BMI Category			
< 18.5	3 (3.26%)	4 (3.51%)	7 (3.40%)
≥ 18.5 and < 25	70 (76.1%)	52 (45.6%)	122 (59.2%)
≥ 25 and < 30	13 (14.1%)	15 (13.2%)	28 (13.6%)
≥ 30 and < 35	6 (6.52%)	15 (13.2%)	21 (10.2%)
≥ 35 and < 40	0 (0%)	19 (16.7%)	19 (9.22%)
≥ 40	0 (0%)	9 (7.89%)	9 (4.37%)
Total Energy Expenditure (kcal/d)			
N	93	114	207
Mean (SD)	2,319.47 (402.15)	2,516.04 (490.24)	2,427.72 (462.24)
Median [Min, Max]	2,333.39 [1,609.00, 3,380.26]	2,448.56 [1,519.36, 3,772.94]	2,380.00 [1,519.36, 3,772.94]
Basal Metabolic Rate Observed (kcal/d)			
N	88	74	162
Mean (SD)	1,367.42 (131.50)	1,380.24 (161.78)	1,373.27 (145.78)
Median [Min, Max]	1,353.23 [1,108.00, 1,873.09]	1,349.64 [1,053.71, 1,865.21]	1,351.37 [1,053.71, 1,873.09]

continued

TABLE H-7 Continued

	Lactating 1–3 mo (*N* = 93)	Lactating 4–6 mo (*N* = 114)	Overall (*N* = 207)
Physical Activity Level Observed (TEE/BMR)			
N	88	39	127
J b^k %PA&	1.70 (0.30)	1.76 (0.33)	1.72 (0.31)
J baf^k X fk) J ^uZ	1.69 [1.02, 2.81]	1.75 [1.08, 2.75]	1.71 [1.02, 2.81]
Physical Activity Level Category Observed			
M I 9	0 (0%)	0 (0%)	0 (0%)
Fk^`qfsb	26 (29.5%)	9 (23.1%)	35 (27.6%)
I l t > `qfsb	17 (19.3%)	6 (15.4%)	23 (18.1%)
> `qfsb	26 (29.5%)	11 (28.2%)	37 (29.1%)
Sbov > `qfsb	17 (19.3%)	11 (28.2%)	28 (22.0%)
M I ; /2	2 (2.27%)	2 (5.13%)	4 (3.15%)
Basal Metabolic Rate Predicted (kcal/d)			
N	92	114	206
J b^k %PA&	1,376.79 (108.79)	6,315.37 (13,812.46)	4,109.79 (10,546.39)
J baf^k X fk) J ^uZ	1,355.57 [1,162.38, 1,718.94]	1,596.89 [1,154.20, 48,810.25]	1,459.41 [1,154.20, 48,810.25]
Physical Activity Level Observed + Predicted			
N	93	114	207
J b^k %PA&	1.70 (0.30)	1.43 (0.56)	1.55 (0.48)
J baf^k X fk) J ^uZ	1.69 [1.02, 2.81]	1.51 [0.04, 2.75]	1.62 [0.04, 2.81]
Physical Activity Level Category Observed + Predicted			
M I 9	0 (0%)	13 (11.4%)	13 (6.28%)
Fk^`qfsb	27 (29.0%)	46 (40.4%)	73 (35.3%)
I l t > `qfsb	18 (19.4%)	19 (16.7%)	37 (17.9%)
> `qfsb	27 (29.0%)	16 (14.0%)	43 (20.8%)
Sbov > `qfsb	19 (20.4%)	18 (15.8%)	37 (17.9%)
M I ; /2	2 (2.15%)	2 (1.75%)	4 (1.93%)

NOTE: BMI = body mass index; BMR = basal metabolic rate; cm = centimeter; DLW = doubly labeled water; kcal/d = kilocalorie/day; kg = kilogram; m = meter; max = maximum; min = minimum; mo = months; PAL = physical activity level; SD = standard deviation; TEE = total energy expenditure.

Appendix I

Characteristics of the DLW Validation Studies

TABLE I-1 Characteristics of 144 Cohorts from 65 Published Studies Included in the Model Validation

	Boy (*N* = 21)	Girl (*N* = 20)
Sex		
Female	0 (0%)	20 (100%)
Male	21 (100%)	0 (0%)
Age		
Mean (SD)	9.97 (4.68)	9.53 (4.14)
Median [Min, Max]	8.50 [3.00, 18.6]	8.10 [3.00, 18.0]
Weight		
Mean (SD)	40.2 (22.4)	37.3 (19.3)
Median [Min, Max]	30.0 [16.4, 88.4]	29.3 [15.9, 85.8]
Height		
Mean (SD)	140 (24.9)	135 (21.1)
Median [Min, Max]	133 [100, 181]	129 [103, 175]
BMI		
Mean (SD)	18.7 (3.91)	18.9 (4.36)
Median [Min, Max]	16.7 [14.4, 27.4]	17.2 [14.9, 33.0]
TEE		
Mean (SD)	2,410 (884)	1,970 (525)
Median [Min, Max]	1,990 [1,290, 4,370]	1,840 [1,150, 3,050]
PAL		
Mean (SD)	1.84 (0.156)	1.81 (0.221)
Median [Min, Max]	1.77 [1.69, 2.07]	1.72 [1.62, 2.21]
Missing	13 (61.9%)	13 (65.0%)
PALCAT		
Active	15 (71.4%)	6 (30.0%)
Very Active	6 (28.6%)	0 (0%)
Low Active	0 (0%)	14 (70.0%)
Inactive	0 (0%)	0 (0%)

NOTE: BMI = body mass index; DLW = doubly labeled water; max = maximum; min = minimum; mo = months; PAL = physical activity level; PALCAT = PAL category; SD = standard deviation; TEE = total energy expenditure.

Man (N = 32)	Woman (N = 71)	Overall (N = 144)
0 (0%)	71 (100%)	91 (63.2%)
32 (100%)	0 (0%)	53 (36.8%)
39.7 (16.6)	34.7 (11.9)	28.7 (16.8)
35.5 [19.0, 94.0]	33.7 [19.4, 94.0]	30.0 [3.00, 94.0]
82.5 (11.9)	71.7 (19.0)	64.7 (24.8)
82.7 [65.0, 107]	67.3 [38.5, 162]	67.2 [15.9, 162]
176 (4.38)	162 (16.9)	158 (22.2)
177 [167, 182]	165 [24.0, 170]	165 [24.0, 182]
26.6 (3.38)	27.0 (6.77)	24.6 (6.54)
26.0 [21.9, 34.9]	24.3 [20.9, 60.3]	24.0 [14.4, 60.3]
3,040 (532)	2,330 (399)	2,450 (636)
3,030 [1,940, 4,370]	2,230 [1,510, 3,850]	2,420 [1,150, 4,370]
1.66 (0.130)	1.67 (0.161)	1.71 (0.172)
1.70 [1.36, 1.90]	1.69 [1.19, 1.98]	1.71 [1.19, 2.21]
18 (56.3%)	46 (64.8%)	90 (62.5%)
14 (43.8%)	17 (23.9%)	52 (36.1%)
4 (12.5%)	6 (8.45%)	16 (11.1%)
9 (28.1%)	25 (35.2%)	48 (33.3%)
5 (15.6%)	23 (32.4%)	28 (19.4%)

Appendix J

Summary of Data Extracted from Systematic Reviews and Other Reviewed Literature

TABLE J-1 Evidence on the Relationship Between Different Measurements of Physical Activity and Energy Expenditure: Systematic Reviews

Author, Year	Number of Studies	Sample Character-istics	Predictor or Intervention or Comparator	Primary Outcome
Adamo et al., 2009	5	47 males and females 1–18 y; White European, U.S. African American, U.S. White	Indirect measures of physical activity included activity diaries or logs, questionnaires, surveys, and recall interviews	Mean difference from DLW in boys and girls combined
Adamo et al., 2009	13	110 males 1–18 y; White European, U.S. African American, U.S. White	Indirect measures of physical activity included activity diaries or logs, questionnaires, surveys, and recall interviews	Mean difference from DLW in boys
Adamo et al., 2009	13	93 females 1–18 y; White European, U.S. African American, U.S. White	Indirect measures of physical activity included activity diaries or logs, questionnaires, surveys, and recall interviews	Mean difference from DLW in girls
Dowd et al., 2018	27	Males and females ≥ 19 y; high-income countries	Self-reported measures of PA included 7-day recall questionnaires, past year recall questionnaires, typical week questionnaires, and PA logs/diaries	Criterion validity of EE estimates compared to 8–15 days of DLW measurement

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Data from studies/substudies reporting on combined male and female data that compared an indirect measure to DLW indicated that indirect measures overestimated physical activity or energy expenditure with a mean percent difference of 22% and a range of –25% to 78%.	Overall, 19 of 24 studies unclearly reported or failed to report between one and five of the 16 components	—	Partially well done/reported
Results for male-only had mean percent differences of 0 (range: –33% to 56%).	Overall, 19 of 24 studies unclearly reported or failed to report between one and five of the 16 components	—	Partially well done/reported
Results for female-only had mean percent differences of –1.2 (range: –43% to 95%).	Overall, 19 of 24 studies unclearly reported or failed to report between one and five of the 16 components	—	Partially well done/reported
Mean percent differences for PA diaries ranged from –12.9% to 20.8%, self-reported PA energy expenditure recalled from the previous 7 days (or typical week) ranging from –59.5% to 62.1%, self-reported PA energy expenditure for the previous month ranged from –13.3% to 11.4%, self-reported PA from the previous 12 months ranged from –77.6% to 112.5%.	Mean AMSTAR score was 5.4 (out of 11)	—	Well done/reported

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Character-istics	Predictor or Intervention or Comparator	Primary Outcome
Dowd et al., 2018	24	Males and females ≥ 19 y; high-income countries	Activity monitor determined energy expenditure	DLW
Dowd et al., 2018	9	Males and females ≥ 19 y; high-income countries	Activity monitor determined PA intensity	Indirect calorimetry and whole-room calorimetry PA intensity
Dowd et al., 2018	31	Males and females ≥19 y; high-income countries	Activity monitor determined energy expenditure	Indirect calorimetry EE
Dowd et al., 2018	3	Males and females ≥ 19y; high-income countries	Pedometer determined EE	DLW
Helmerhorst et al., 2012	2	111 males and females < 18 y; high-income countries	Physical activity questionnaires	DLW

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
The range of MPD observed in studies that examined the criterion validity of activity monitor–determined energy expenditure ranged from –56.59% to 96.84%. However, a trend was apparent for activity monitor–determined energy expenditure to underestimate the criterion measure.	Mean AMSTAR score was 5.4 (out of 11)	—	Well done/reported
For LIPA, the MPD ranged from –79.8% to 429.1%. For MPA, MPD ranged from –50.4% to 454.1%, while estimates for VPA ranged from –100% to 163.6%. Energy expenditure estimates from activity monitoring devices for total PA were compared against indirect calorimetry estimates, where MPD ranged from –41.4% to 115.7%. The MPD range for activity monitor-determined total energy expenditure compared with whole room calorimetry were narrower (–16.7% to –15.7%).	Mean AMSTAR score was 5.4 (out of 11)	—	Well done/reported
Estimated energy expenditure was compared between activity monitors and indirect calorimetry (kcal over specified durations; [–68.5% to 81.1%]); (METs over specified durations; [–67.3% to 48.4%]). A single study compared the estimated energy expenditure from 5 different activity monitors and indirect calorimetry at incremental speeds (54, 80, 107, 134, 161, 188, and 214 $m \cdot min^{-1}$) in both men and women (MPD ranged from –60.4% to 90.8%).	Mean AMSTAR score was 5.4 (out of 11)	—	Well done/reported
In free-living studies that examined the criterion validity of pedometer determined energy expenditure, pedometers were worn for 2 to 8 days (–62.3% to 0.8%).	Mean AMSTAR score was 5.4 (out of 11)	—	Well done/reported
For PA EE, Spearman *r* ranged from 0.09 to 0.45 and MD was 0.46 to 0.76 kg/kg/d. For TEE, Spearman *r* ranged from 0.49 to 0.65; MD 2,800 kJ/day.	—	—	Not well done/reported

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Helmerhorst et al., 2012	6	239 males and females 18–65 y; high-income countries	Physical activity questionnaires	DLW
Helmerhorst et al., 2012	2	86 males and females > 65 y; high-income countries	Physical activity questionnaires	DLW
Jeran et al., 2016	24	1,148 males and females ≥ 19 y; mix of general population, soldiers, and patients (COPD and cancer); high-income countries	Assess whether study or accelerometer device characteristics influence the association between accelerometer-derived physical activity output and DLW-derived AEE	Crude R^2 accelerometer output vs. AEE or AEE per kg
O'Driscoll et al., 2020	60	1,946 males and females ≥ 19 y; high-income countries	EE estimate of wrist-worn or arm devices (40 different devices; 33 wrist-worn)	—
O'Driscoll et al., 2020	60	1,946 males and females ≥ 19 y; high-income countries	TEE estimate of wrist-worn or arm devices (10 different devices)	—

Quantitative or Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
For PA EE, Spearman r = 0.39 and MD was −12.9 kJ/day from one study. Four studies reported TEE and Spearman r ranging from 0.15 to 0.67; Pearson r ranged from 0.12 to 0.58; MD ranged from –3,451.9 to 7,455 kJ/day. One study reported PAL, and the Pearson r ranged from 0.34 to 0.69.	—	—	Not well done/ reported
For TEE, Spearman r ranged from 0.10 to 0.64; Pearson r ranged from 0.11 to 0.65; MD ranged from 435 to 3,146 (men) and 37 to 2,037 (women) kJ/day.	—	—	Not well done/ reported
Crude R^2 ranged from 0.043 to 0.80 with a median of 0.26. Crude R^2 did not significantly differ by accelerometer recording period (≤1 week vs. 41 week), body position (trunk vs. limbs), wear time (waking hours vs. 24 hours), accelerometer output type (uniaxial vs. triaxial outputs) or accelerometer output metrics (counts vs. steps vs. other) (all p-values of Mann–Whitney U-test and Kruskal–Wallis test, 40.05). There was a significant inverse association between crude R^2 and sample size (r = –0.45, p = .03). There was no significant correlation between crude R^2 and mean age of participants (r = 0.16, p = .44).	—	—	Not well done/ reported
Overall, devices underestimated EE (ES, –0.23, 95% CI, –0.44 to –0.03; n = 104; p = .03) and showed significant heterogeneity between devices (I^2, 92.18%; $p \leq .001$).			
The pooled effect for TEE showed a significant underestimation of EE (ES: –0.68; 95% CI, –1.15 to –0.21; n = 16; p = .005), and significant heterogeneity was observed between devices (I^2, 92.71%; $p < .01$). The SWA p3 did not differ significantly from criterion measures and showed significant heterogeneity (I^2, 94.20%; p = .001).	Median score of 13; 1 low-quality, 48 moderate-quality, and 11 high-quality	—	Partially well done/ reported

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Pisanu et al., 2020	5	734 males and females ≥ 19 y with overweight and obesity; high-income countries	REE estimated from wearable accelerometer-based devices	—
Pisanu et al., 2020	9	339 males and females ≥ 19 y with overweight and obesity; high-income countries	PA EE estimated from wearable accelerometer–based devices during different structured physical activities	—

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
One study obtained an underestimation of REE SWA, although the statistical significance was not specified. However, a significant overestimation of SWA was observed in all four other studies. Pearson's correlation coefficient was reported in three studies, in which it ranged between 0.58 (obtained in women) and 0.88 (obtained in the whole population). Results of Bland–Altman analysis revealed the tendency of the bias to increase as the REE increased across participants. Authors did not find any relationship between the bias and age, BMI, fat-free mass, total body water, and extracellular water of individuals. Bland–Altman plots indicated that SWA systematically overestimated REE in women displaying low REE values and underestimated REE in women displaying high REE values.	Risk of bias was judged as low	—	Well done/reported (or partially well done/reported if heterogeneity issue is important)
A general trend toward overestimation can be noticed. However, the study protocol differs greatly among the included studies.	Risk of bias was judged as low	—	Well done/reported (or partially well done/reported if heterogeneity issue is important)

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Pisanu et al., 2020	5	185 males and females ≥ 19 y with overweight and obesity; high-income countries	TEE or PA EE free-living from wearable accelerometer-based devices	—

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
The accuracy of the Caltrac uniaxial accelerometer in the measurement of TEE was evaluated: even if the accuracy of the instrument was good at a group level, at the individual level, differences were large. An underestimation of EE in free-living conditions was obtained in one study. RT3 limits of agreement were smaller than TriTrac-R3D, but presented limitations at individual levels. Bland–Altman plots showed that SWA and IDEEA accurately estimated TEE, and the IDEEA accelerometer accurately measured AEE. On the other hand, the performance of Actical was low. Accuracy of TEE and AEE estimates of the SWA, using software versions 6.1 and 5.1 in a sample of older participants (78–89 years old), who were overweight as a group. Both versions showed high Pearson's correlation coefficients ($r > 0.75$) for TEE. On the other hand, AEE was underestimated by both versions 6.1 and 5.1. Nevertheless, Bland–Altman plots revealed no systematic bias when considering both TEE and AEE.	Risk of bias was judged as low	—	Well done/reported (or partially well done/reported if heterogeneity issue is important)

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Plasqui et al., 2013	25	944 males and females; high-income countries	Validity of wearable PA monitor estimates of EE	—
Sharifzadeh et al., 2021	30	3,877 males and females; high-income countries	Physical activity questionnaire TEE (50 questionnaires)	—
Sharifzadeh et al., 2021	15	2,058 males and females; high-income countries	Physical activity questionnaire AEE (35 questionnaires)	—

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Mean differences in TEE or AEE between DLW and the accelerometer were often small on the group level, but the limits of agreement (2 SD) were usually large. Observed correlations between PAL and activity counts vary between 0.06 (Lifecorder) and 0.68 (TracmorD). Interpreting correlations between AEE or TEE and activity counts becomes more difficult as body mass and other characteristics are the main determinants of EE. Output from the 3dNX accelerometer significantly increased the prediction of TEE in addition to FFM. The Tracmor significantly contributed to the prediction of TEE after correcting for sleeping metabolic rate, body mass, or FFM. Likewise, the RT3 significantly contributed to the prediction of TEE and AEE after correction for subject characteristics. When AEE is expressed per kg body mass, correlations with activity counts vary between 0.37 (Actigraph) and 0.79 (Tracmor).	—	—	Not well done/ reported
The weighted mean difference was not significant between TEE_{DLW} –TEE_{PAQ} (WMD, –243, 95% CI, –841.4–354.6; I^2, 97.9%, $p < .0001$).	—	—	Not well done/ reported
A significant difference was found between AEEs examined by various indirect measures and the direct measures derived from DLW (WMD, 414.6; 95% CI, 78.7–750.5; I^2, 92%, $p < .001$) in which AEE assessed by DLW was higher than that measured by PAQ.	—	—	Not well done/ reported

continued

TABLE J-1 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Tudor-Locke et al., 2002	8	Males and females; high-income countries	Pedometer versus energy expenditure	—
Tudor-Locke et al., 2002	8	Males and females; high-income countries	Pedometer versus energy expenditure	—

NOTE: AEE = activity energy expenditure; COPD = chronic obstructive pulmonary disease; DLW = doubly labeled water; EE = energy expenditure; ES = effect size; FFM = fat-free mass; IDEEA = Intelligent Device for Energy Expenditure and physical Activity; kcal = kilocalories; kg = kilogram; kJ = kilojoule; LIPA = light-intensity physical activity; MD = mean difference; MET = metabolic equivalent of task; MPA = moderate-intensity physical activity; MPD = mean percentage difference; PA = physical activity; PAL = physical activity level; PAQ = physical activity questionnaire; REE = resting energy expenditure; SD = standard deviation; SWA = SenseWear Armband; TEE = total energy expenditure; VPA = vigorous-intensity physical activity; WMD = weighted mean difference; y = years.

Quantitative or Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Although a single study comparing pedometer outputs with energy expenditure derived from doubly labeled water reported a significant correlation of $r = 0.61$ in a patient population, two other studies reported no significant correlations in different populations (no reported *r* values).	—	—	Not well done/ reported
Pedometers generally correlate with indirect calorimetry from $r = 0.49$ to 0.81	—	—	Not well done/ reported

TABLE J-2 Evidence on the Association of Macronutrient Composition of the Diet on Metabolic Efficiency (Energy Usage or Energy Expenditure): Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome	Quantitative Finding(s)
Ludwig et al., 2021	29	617 male and female adults 19–50 y	Low vs. high carbohydrate diet	TEE	Lower carbohydrate diet had lower TEE for studies < 2.5 weeks –50.0 kcal (–77.4, –22.6) Higher TEE among > 2.5 weeks 135.5 kcal (72.0, 198.7). Sensitivity analysis produced similar results
Park et al., 2020	15	Adults 19–50 y with obesity or lean/normal weight	—	—	—
Quatela et al., 2016	19 (related to energy)	Male and female adults 19 y and older	Total energy intake	DIT; RMR	The effect of energy intake on DIT (coefficient, 0.011; standard error, 0.0013; p < .001; 95% CI, 0.0083–0.014)
Cisneros et al., 2019	15	210 male and female adults 19 y and older	type of fatty acid	DIT or EE	No conclusion can be drawn

Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
Among trials < 2.5 weeks, the lower-carbohydrate diets slightly reduced TEE.	—	I^2, 69.8%; $p < .001$	Not well done/reported
Among trials of > 2.5 weeks, the lower-carbohydrate diet substantially increased TEE—by ~50 kcal/d for every 10% decrease in carbohydrate as % EI—with minimal residual heterogeneity.		I^2, 26.4%; $p = .255$	
Many studies reported that the main determinant of DIT is the energy content of food, followed by the protein fraction of food. The thermic effect of alcohol is similar to that of protein. Therefore, the main determinants of DIT are the energy content and protein fraction of the diet.	—		Not well done/reported
This model shows that DIT (kJ) increases significantly ($p < .001$) when the kJ content of meals increases, although this increase is of a small magnitude (coefficient, 0.011). This model predicts that for every 100-kJ increase in energy intake, DIT increases by 1.1 kJ/h. Model 2 produced similar results. (47.4% variance explained in model 1; 70.6% in model 2)	—		Not well done/reported
—	—	—	Not well done/reported

continued

TABLE J-2 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome	Quantitative Finding(s)
Wycherley et al., 2012	4	40 participants	high protein (low fat) vs standard protein (low-fat)	REE (secondary outcome)	≥ 12 weeks mean difference was 130 kJ/day (range –205.13–465.13); < 12 weeks 838 kJ/day (228.83, 1,447.17). Across all time 595.50 kJ/day (range, 66.95–1,124.05)

NOTE: CI = confidence interval; DIT = diet-induced thermogenesis; EE = energy expenditure; EI = energy intake; kJ = kilojoule; REE = resting energy expenditure; RMR = resting metabolic rate; TEE = total energy expenditure; y = years.

TABLE J-3 Evidence on the Association of Body Composition on Metabolic Efficiency (Energy Usage or Energy Expenditure): Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome	Quantitative Finding(s)
Bailly et al., 2021	29 for any meta-analysis. 15 assessed TEE (2 using DLW), RMR indirect calorimeter (*n* = 14) and 9 with portable devices, physical activity measured with accelerometer (*n* = 5)	Male and female adults 19–50 y; included pregnant women	CT vs. anorexia nervosa or normal BMI	TEE, RMR, RMR/FFM, RQ, AEE, PAL	See Table 7 in Bailly et al., 2021: comparison of CT vs. C Comment: Meta-analysis done only in women, no cohort studies included because risk of bias too high

NOTE: AEE = activity energy expenditure; BMI = body mass index; C = controls; CT = constitutional thinness; DLW = doubly labeled water; FFM = fat-free mass; PAL = physical activity level; REE = resting energy expenditure; RMR = resting metabolic rate; RQ = respiratory quotient; TEE = total energy expenditure; y = years.

Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
There was significantly less reduction in REE with a high-protein diet	Provided risk of bias for each included study	I^2, 64%	Not well done/ reported

Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
See Table 9 in Bailly et al., 2021: CT individuals have a lower TEE, REE compared to normal weight; No diff in RQ, AEE, PAL between CT and normal weight; RMR/FFM trend of significant difference such that C < CT (p = .083)	—	—	Partially well done/reported

TABLE J-4 Evidence on the Effect or Association of Weight Cycling with Metabolic Efficiency (Energy Usage, Expenditure) and Health Outcomes: Systematic Reviews and Observational Studies

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome	Quantitative Finding(s)
Zou et al., 2021	14	253,766 males and females 19 y and older	Weight cycling	Type 2 diabetes mellitus	RR, 1.23; 95% CI, 1.07 to 1.41; $p = .003$
Zou et al., 2019	20	341,395 males and females 19 y and older	Weight cycling	All-cause mortality	RR, 1.41; 95% CI, 1.27 to 1.57; $p = .001$
El Ghoch et al., 2018	—	38 males and females 19–50 y with obesity	Weight cycling	REE	No change in REE: 1,840.2 ± 397.9 vs. 1,831.9 ± 408.9, $p = .78$
Nymo et al., 2019	—	38 males and females 19–50 y	Weight cycling	REE	REE only 70 kcal lower than baseline
Bosy-Westphal et al., 2013	—	47 males and females 19–50 y with obesity	Very-low-calorie diet	REE	REE adjusted for changes in organ and tissue masses, remains reduced on weight cyclers, $p < .01$.
Dombrowski et al., 2014	45	7,788 males and females 19–50 y with overweight and obesity	Diet	Weight cycling	N/A

Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Weight cycling increases risk for new-onset diabetes by 23% in persons with BMI < 30	—	I^2, 73.9%	Partially well done/reported
Weight cycling increases risk for all-cause mortality by 41%, CVD mortality by 36%, and risk for hypertension by 35% in adults	—	I^2, 78.1%	Well done/ reported
Weight cycling does not appear to adversely affect REE in adults with morbid obesity (BMI ≥ 40)	—	—	—
Although weight loss associated with reduced REE, there was no association between REE and weight cycling in adults with class I/II obesity	—	—	—
In overweight and obese adults age 22–45, weight cycling shows a reduced REE when adjusted for organ and tissue mass.	—	—	—
Behavioral interventions for weight loss maintenance in obese adults reduces risk for weight regain/ cycling.	—	I^2, 75%	Well done/ reported

continued

TABLE J-4 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome	Quantitative Finding(s)
Turicchi et al., 2019	43	2,379 males and females 19 y and older with overweight and obesity	Diet	Weight cycling	Amount of weight loss: R^2, 0.29; $p <$ .001; Rate of weight loss (R^2, 0.06; p = .049)
Fothergill et al., 2016	—	14 males and females 19–50 y with class III obesity	Diet and exercise	TEE and REE	REE reduced 704 ± 427 kcal/d below baseline at 6 years after weight loss ($p <$ .0001)
Zhang et al., 2019	4	92,063 females 19 y and older	Weight cycling	Endometrial cancer	Odds ratio, 1.23 to 2.33

NOTE: BMI = body mass index; CI = confidence interval; CVD = cardiovascular disease; N/A = not applicable; REE = resting energy expenditure; RR = relative risk; TEE = total energy expenditure; y = years.

Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
When controlling for the rate of weight loss, the amount of weight loss significantly predicts weight regain.	1 study high risk of bias, 4 studies low risk of bias, 38 medium risk of bias	Tau^2	Not done/reported
Metabolic adaptation in morbid obesity is associated with the degree of weight loss; REE and TEE remain reduced for 6 years after weight loss even with weight regain or increased physical activity.	—	—	—
Weight cycling is associated with 1.2- to 2.3-fold increased risk for endometrial cancer in females age ≥ 18y.	—	—	Partially well done/reported

TABLE J-5 Evidence on the Effect of Race or Ethnicity on Energy Expenditure

Author, Year	Populations	Sex	Life Stage
Albu et al., 1997	B/W	F	Adults
Foster et al., 1999	B/W	F	Adults
Jakicic and Wing, 1998	B/W	F	Adults
Mika Horie et al., 2009	B/W	F	Adults
Reneau et al., 2019	B/W	F/M	Adults
Shook et al., 2014	B/W	F	Adults
Olivier et al., 2016	B/W	F	Adults
Sharp et al., 2002	B/W	F/M	Adults
Spaeth et al., 2015	B/W	F/M	Adults
Vander Weg et al., 2004	B/W	F	Adults
Wang et al., 2010	B/W	F	Adults
Adzika Nsatimba et al., 2016	B/W	F/M	Adults
Forman et al., 1998	B/W	F	Adults
Santa-Clara et al., 2006	B/W	F	Adults
Vander Weg et al., 2000	B/W	F/M	Adults
Martin et al., 2004	B/W	F/M	Adults
Most et al., 2018	B/W	F	Adults
Manini et al., 2011	B/W	F/M	Adults
Désilets et al., 2006	B/W	F/M	Adults
Rush et al., 1997	Maori/W	F	Adults
Wouters-Adriaens and Westerterp, 2008	Asian/W	F/M	Adults
Byrne et al., 2003	B/W	F	Adults
Hunter et al., 2000	B/W	F	Adults
Deemer et al., 2010	Hispanic/W	F	Adults

Conclusion Category	Mean Difference (kcal/d)	General Conclusions
REE difference, adjusted	180	Lower REE in B vs. W
REE difference, adjusted	135	Lower EE in B vs. W
REE difference, adjusted	172	Lower EE in B vs. W
REE difference, adjusted	200	Lower EE in B vs. W
REE difference, adjusted	144	Lower REE in B vs. W, attenuated with inclusion of trunk lean body mass
REE difference, adjusted	101	Lower EE in B vs. W, also lower fitness levels
REE difference, adjusted	140	Lower EE in B vs. W
REE difference, adjusted	80	Lower EE in B vs. W, CARDIA study
REE difference, adjusted	100	Lower EE in B vs. W
REE difference, adjusted	65	Prediction equation, lower EE in B
REE difference, adjusted	121	Lower EE in B vs. W
REE difference, adjusted	250	Lower EE in B vs. W
REE difference, adjusted	200	Lower EE in B vs. W
REE difference, adjusted	80	Lower EE in B vs. W
REE difference, adjusted	78	Lower EE in B vs. W, no body composition; smokers
REE difference, adjusted	135	Lower EE in B vs. W; diabetes status
REE difference, adjusted	81	Early pregnancy; lower REE in B vs. W
REE difference, adjusted	50	European admixture associated with higher REE; elderly
REE difference, adjusted	110	Lower EE in B vs. W
REE difference, adjusted	119	Lower REE in Maori vs. W
REE no difference, adjusted	0	Equal REE after adjusting for body composition
REE no difference, adjusted	0	Equal REE after adjusting for detailed composition
REE no difference, adjusted	0	Equal EE after adjusting for trunk lean body mass
REE no difference, adjusted	0	Equal REE but unadjusted

continued

TABLE J-5 Continued

Author, Year	Populations	Sex	Life Stage
Soares et al., 1998	Indian/W	F/M	Adults
Weyer et al., 1999	Pima/W	F/M	Adults
Javed et al., 2010	B/W	F/M	Adults
Jones et al., 2004	B/W	F	Adults
Gallagher et al., 2006	B/W	F/M	Adults
Gallagher et al., 1997	B/W	F/M	Adults
Song et al., 2016	Chinese/Indian/ Malay	M	Adults
Tranah et al., 2011	B/W	F/M	Adults
Glass et al., 2002	B/W	F	Adults
DeLany et al., 2014	B/W	F	Adults
Dugas et al., 2009	B/W	F	Adults
Lam et al., 2014	B/W	F/M	Adults
Weinsier et al., 2000	B/W	F	Adults
Most et al., 2018	B/W	F	Adults
Blanc et al., 2004	B/W	F/M	Adults
Walsh et al., 2004	B/W	F	Adults
Weyer et al., 1999	Pima/W	F/M	Adults
Katzmaryk et al., 2018	B/W	F/M	Adults
Hunter et al., 2000	B/W	F	Adults
Kushner et al., 1995	B/W	F	Adults
Lovejoy et al., 2001	B/W	F	Adults
Saad et al., 1991	Pima/W	M	Adults
Christin et al., 1993	Pima/W	M	Adults
Fontvieille et al., 1994	Pima/W	F/M	Adults

Conclusion Category	Mean Difference (kcal/d)	General Conclusions
REE no difference - adjusted	0	Equal EE after adjusting for body composition
REE no difference - adjusted	0	Higher TEE in Pima vs. W, equal SMR
REE no difference - HMRO	0	Equal after adjusting for organ metabolic rate
REE no difference - HMRO	0	Equal after adjusting for skeletal muscle mass
REE no difference - HMRO	0	Organ sizes/metabolic rates
REE no difference - HMRO	0	Body composition differences
REE no difference - HMRO	0	Lower EE in Asians, equal when adjusting for trunk lean body mass
REE no difference - mtDNA	0	Equal EE after adjusting for mtDNA haplotypes; elderly
REE no difference -unadjusted	0	Equal EE
TEE difference - adjusted	233	Lower EE B vs. W
TEE difference - adjusted	105	Lower EE in B vs. W
TEE difference - adjusted	52	Lower EE in B vs. W, develop predictive equation
TEE difference - adjusted	138	Lower EE in B vs. W
TEE difference - adjusted	230	Lower SMR and TEE in B vs. W; early pregnancy
TEE difference - adjusted	200	Lower TEE and REE in B vs. W; elderly
TEE difference - unadjusted	116	Lower TEE in B vs. W, unadjusted
TEE difference (Pima higher)	-44	
TEE no difference - adjusted	0	Lower EE in B vs. W
TEE no difference - adjusted	0	
TEE no difference - adjusted	0	Equal TEE after adjusting body composition
TEE no difference - adjusted	0	Lower SMR in B vs. W, equal TEE
TEE no difference - adjusted	0	Equal 24-hr EE, difference in sympathetic nervous system activity
TEE no difference - adjusted	0	Equal EE, norepinephrine turnover as predictor
TEE no difference - adjusted	0	Lower SMR in Pimas

continued

TABLE J-5 Continued

Author, Year	Populations	Sex	Life Stage
Tershakovec et al., 2002	B/W	F/M	Children
Wong et al., 1996	B/W	F	Children
Bandini et al., 2002	B/W	F	Children
Morrison et al., 1996	B/W	F	Children
Yanovski et al., 1997	B/W	F	Children
Wong et al., 1999	B/W	F	Children
Sun et al., 2001	B/W	F/M	Children
McDuffie et al., 2004	B/W	F/M	Children
Pretorius et al., 2021	B/W	F/M	Children
Sun et al., 1998	B/W	F/M	Children
Broadney et al., 2018	B/W	F/M	Children
Hanks et al., 2015	B/W	M	Children
Rush et al., 2003	Maori/Pacific Islander/W	F/M	Children
Spurr et al., 1992	Mestizo/B/ Amerindian	F/M	Children
Goran et al., 1995	Mohawk/W	F/M	Children
Fontvieille et al., 1992	Pima/W	F/M	Children
Bandini et al., 2002	B/W	F	Children
DeLany et al., 2002	B/W	F/M	Children
Dugas et al., 2008	Hispanic/W	F	Children
Sun et al., 1998	B/W	F/M	Children
Goran et al., 1998	B/W/Mohawk/ Guatemalan	F/M	Children
Goran et al., 1995	Mohawk/W	F/M	Children

NOTE: AEE = activity energy expenditure; B = Black; BMD = bone mineral density; EE = energy expenditure; F = female; HMRO = high-metabolic-rate organs; kcal/d = kilocalorie per day; M = male; mtDNA = mitochondrial DNA; REE = resting energy expenditure; SMR = sleeping metabolic rate; TEE = total energy expenditure; W = White.

Conclusion Category	Mean Difference (kcal/d)	General Conclusions
REE difference - adjusted	77	Lower EE in B vs. W, attenuated with inclusion of trunk lean body mass
REE difference - adjusted	52	Testing REE predictive equations; greater overestimation in B
REE difference - adjusted	62	Lower REE,TEE, AEE in B vs. W
REE difference - adjusted	120	Lower REE in B vs. W
REE difference - adjusted	92	Lower REE in B vs. W
REE difference - adjusted	79	Lower REE in B vs. W
REE difference - adjusted	45	Lower REE in B vs. W
REE difference - adjusted	36	Lower EE in B vs. W; developed predictive equation
REE difference - adjusted	91	Lower EE in B vs. W
REE no difference - adjusted	0	Equal EE
REE no difference - adjusted	0	Equal REE after adjusting for truncal composition
REE no difference - adjusted	0	Looking at BMD as predictor
REE no difference - adjusted	0	Equal REE across groups
REE no difference - adjusted	0	Equal EE across groups
REE no difference - adjusted	0	Lower EE in W vs. Mohawk
REE no difference - adjusted	0	Equal REE
TEE difference - adjusted	110	Lower TEE in B vs. W; prepubertal and pubertal
TEE difference - adjusted	62	Lower EE B vs. W
TEE difference - adjusted	60	Equal REE, lower AEE in Hispanic
TEE no difference - adjusted	0	
TEE no difference - adjusted	0	Equal REE across groups, lower AEE in Guatemalans
TEE no difference - adjusted	0	

TABLE J-6 Evidence on How Physical Activity and Energy Expenditure Change Across the Life Span: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Craigie et al., 2011	22	11,889 males and females, children and adults from high-income countries	Association between physical activity levels at baseline and follow-up	—
Craigie et al., 2011	13	4,999 males and females, children and adults from high-income countries	Maintenance of relative position—physical activity	—
Craigie et al., 2011	10	17,654 males and females, children and adults from high-income countries	The probability of being physically active at follow-up according to activity at baseline	—

Quantitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
In general, the correlation coefficients tended to be stronger in the European studies (ranging from –0.01 to 0.47), compared with Canadian (–0.1 to 0.24), United States (0.01 to 0.17) or Australian studies (0.04 to 0.07). In males, coefficients varied between –0.1 (nonsignificant, at 22-year follow-up) and 0.47 ($p <$ 0.001 for frequency of activity over 8 years). In females, these ranged between –0.04 (nonsignificant over 7 years) and 0.37 ($p < .001$ over 6 years).	—	—	Not well done/ reported
Over 5–8 years follow-up from adolescence between 44% and 59% maintained their tertile position for activity, with higher proportions for males than for females. In the Cardiovascular Risk in Young Finns study participants, the probability of 9-to-18-year-olds remaining active 6 years later (44% of all participants) was significantly weaker than the probability of remaining sedentary (57% of all participants) ($p = .002$).	—	—	Not well done/ reported
Four studies reported the probability of being physically active in adulthood using odds ratios. However, a comparison of their findings is complicated by the variation in categories used in their analyses. The Amsterdam Growth and Health Longitudinal Study reported general daily physical activity: those in the lowest quartile for daily physical activity at 13 years old were 3.6 times more likely (95% CI, 2.4–5.4) to be in the lowest quartile 14 years later than those in the 3 higher quartiles at baseline.	—	—	Not well done/ reported

continued

TABLE J-6 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Foulds et al., 2013	8	915 males and females; Native American population in Canada and United States	Average PALs—adults	PAL via DLW and metabolic chamber
Foulds et al., 2013	2	408 males and females; Native American population in Canada and United States	Average PALs—adults	PAL via DLW and metabolic chamber
Foulds et al., 2013	5 published from 1980 to 1989, 14 from 1990 to 1999, and 20 from 2000 to 2011	> 100,000 males and females; Native American population in Canada and United States	Physical activity change over time	PAL via self-report

Quantitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
Overall average total energy expenditure among Native American adults was found to be 10.53 MJ, with 2.28 MJ of activity energy expenditure. Overall, Native American adults were found to have PAL ratios averaging 1.48.	Citations included in the physical activity behavior assessment consisted of a range of grades from 1A to 3B and an average quality score of 11 out of 15 (range, 6–14)	—	Partially well done/reported
Among children at age 5 years, overall average total energy expenditure was found to be 5.93 MJ, with 1.17 MJ of activity energy expenditure, resulting in a PAL ratio of 1.42. Results among other ages of children/youth are not available in the literature.	Citations included in the physical activity behavior assessment consisted of a range of grades from 1A to 3B and an average quality score of 11 out of 15 (range, 6–14)	—	Partially well done/reported
More recent reports of physical activity behavior among Native American adults identify individuals as being less active than in the 1990s. Overall, greater proportions of Native American adults from 2000 to 2011 reported inactive levels of activity compared to earlier assessments, with lower proportions reporting insufficient PALs.	Citations included in the physical activity behavior assessment consisted of a range of grades from 1A to 3B and an average quality score of 11 out of 15 (range, 6–14).	—	Partially well done/reported

continued

TABLE J-6 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Tanaka et al., 2014	10	7,238 males and females; children and adolescents; from high-income countries	Longitudinal changes in overall sedentary behavior	Average sedentary behavior change per year via wearable devices

NOTE: CI = confidence interval; DLW = doubly labeled water; MJ = megajoule; PAL = physical activity level.

TABLE J-7 Evidence on the Effect of BMI (and Other Measures of Adiposity) on Energy Balance or Energy Expenditure: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Ashtary-Larky et al., 2020	7	361 males and females 19 y and older with overweight and obesity	Gradual weight loss	Weight change
Cheng et al., 2016	12	1,499 males and females 9–18 y	Pubertal	REE
Nunes et al., 2022	33	2,528 males and females 19 y and older	Weight loss	REE or TEE

Quantitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
The follow-up duration ranged from 1.0 to over 10.0 years. The age of the participants at baseline ranged from 3.8 to 13.2 years. The overall percentage daily sedentary behavior change per year ranged from –3.8% to 12.5% for boys and from –2.5% to 12.7% for girls, with a weighted mean increase of daily sedentary behavior of +5.7% in boys and 5.8% in girls, equivalent to additional approximately 30 min of daily accelerometer-measured sedentary behavior per year.	Study methodological quality was rated as high with all 10 papers rated as ≥70%	—	Partially well done/reported

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Gradual weight loss preserved REE by ~100 kcals compared to rapid weight loss	Gradual weight loss produces less reduction in REE than rapid weight loss and a greater loss of fat mass and percent body fat.	3/7 low	—	Partially well done/reported
REE increases 12% and TEE increases 16% during puberty	Both REE and TEE are significantly higher during puberty.	Medium	—	Partially well done/reported
REE and TEE show up to 20% greater decrease than predicted.	In adults, there is adaptive thermogenesis with weight loss leading to a greater than predicted decrease in energy expenditure.	Low to medium	—	Partially well done/reported

continued

TABLE J-7 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Schwartz and Doucet, 2010	90	2,996 males and females 19 y and older with overweight and obesity	Diet or diet plus exercise or diet plus pharmacological intervention	REE
Dhurandar et al., 2015	32	1,680 males and females 19–50 y with normal weight, overweight, and obesity	Diet	Compensation
Kee et al., 2012	20	Males and females 19–50 y with morbid obesity (BMI ≥ 40)	BMI	REE
Nunes et al., 2021		94 males and females 19 y and older with overweight and obesity	Diet; calorie restriction averaged 270 kcal/d	REE
Schwartz et al., 2012	90	815 males and females 19 y and older with overweight and obesity	Diet or diet plus exercise or diet plus weight loss intervention	REE

NOTE: BMI = body mass index; kcal = kilocalorie; kg = kilogram; REE = resting energy expenditure; TEE = total energy expenditure; y = years.

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
REE decreases 15 kcal/kg during weight loss.	The 15-kcal/kg decrease in REE during weight loss does not differ by sex. Short interventions (2–6 weeks) have greater decrease in REE than long intervention (> 6 weeks).	—	—	Not well done/reported
Diet restriction results in 12–44% less weight loss than predicted.	Energy compensation (intake and/or expenditure) leads to less weight loss than predicted with diet restriction.	Medium	—	Not well done/reported
REE ranges 1,800–2,600 kcal in adults with BMI ≥ 40	REE increases with increasing BMI in morbid obesity (BMI ≥ 40).	—	—	Not well done/reported
Reduction in REE ranges –70 to –220 kcal/d more than predicted.	Adaptive thermogenesis occurs with moderate weight loss of 5%.	—	—	Partially well done/reported
Reduction in REE 29.1% greater than predicted by Harris-Benedict equation.	Reduction in REE greater than predicted from Harris-Benedict equation, but Harris-Benedict equation after weight loss may overestimate energy intake needs for weight maintenance.	—	—	Not well done/reported

TABLE J-8 Evidence on How the Increase in Tissue Deposition Associated with Growth During Infancy, Childhood, and Adolescence Influences, Effects, or Contributes to Energy Requirements

Author, Year	*N*	Sex	Age (SD)	Ethnicity
DeLany et al., 2006	28	F	10.7 (0.7)	Black
	25	F	10.6 (0.4)	White
	31	M	10.9 (0.8)	Black
	29	M	10.9 (0.6)	White
Plachta-Danielzik et al., 2008	680	M	6–10 y	
	684	F	6–10 y	
	254	M	10–14 y	
	260	F	10–14 y	
Wells and Davies, 1998	49	41% M	1.5 mo	White
	92	59% F		
	37			
	36			
	18			

NOTE: F = female; g = gram; kcal = kilocalorie; kg = kilogram; M = male; mo = months; SD = standard deviation; wk = weeks; y = years.

TABLE J-9a Evidence on How the Increase in Tissue Deposition Associated with Pregnancy Influences, Effects, or Contributes to Energy Requirements: Nonsystematic Reviews

Author, Year	*N*	Age (SD)	BMI Status	Ethnicity
Catalano et al., 1998	6 normal, 10 GDM/IGT	31.8 y (5.5)	20.8	—
Kopp-Hoolihan et al., 1999	10	29.1 y (5)	23.1	—
Berggren et al., 2015	11	29 y (median)	23.8	10 White 1 non-White
Okereke et al., 2004	8 NGT, 7 GDM	NGT 31.6 y (3.4)	Obese > 25% body fat, 8 NGT 26.2	—
Abeysekera et al., 2016	26	—	—	—

NOTE: BMI = body mass index; g = gram; FFM = fat-free mass; FM = fat mass; GDM = gestational diabetes mellitus; IGT = impaired glucose tolerance; kcal = kilocalorie; kg = kilogram; NGT = normal glucose tolerance; SD = standard deviation; y = years.

Weight Gain g/day (SD)	Protein Gain g/day (SD)	FFM Gain g/day (SD)	FM Gain g/day (SD)	Energy Deposition kcal/day (SD)
10.7 (4.3)		8.1 (1.6)	2.6 (3.6)	32.72
10.80 (4.7)		7 (2.3)	3.8 (3.3)	42.64
12.8 (5.2)		9.2 (4.3)	3.5 (5)	42.22
9.7 (6.1)		7.5 (4.3)	2.2 (5)	28.38
12.2 kg/4 y		10.6 kg/4 y	1.8 kg/4 y	19.3 (50)
12.7 kg/4 y		10.0 kg/4 y	2.7 kg/4 y	24.5 (50)
21.5 kg/4 y		18.5 kg/4 y	2.9 kg/4 y	31.8 (50)
18.4 kg/4 y		12.5 kg/4 y	5.7 kg/4 y	45.6 (50)
0.24 kg/wk (0.08)	3.3 (1.4)		14.4 (3.2)	152.0 (4.8)
0.2 (0.1)	2.8 (1.7)		12.8 (3.7)	134.3 (4.3)
0.12 (0.1)	2.5 (1.7)		3.7 (4)	46.6 (7.6)
0.11 0.11)	2.4 (1.9)		3.1 (5.2)	42.8 (9.1)
0.09 (0.09)	2.1 (1.6)		1.7 (3.3)	28.0 (9.1)

Gestational Weight Gain g/day (SD)	Protein Gain g/day (SD)	FFM Gain g/day (SD)	FM Gain g/day (SD)
13.5	—	7.3 kg from preconception to 36 weeks	2 kg from preconception to 36 weeks
11.6 kg at 36 weeks (4.3)	—	—	4.5 kg from preconception to 34/36 weeks
17.5 median from preconception to 34/36 weeks	—	12.2 (median)	3.5 kg (median)
12.7 kg NGT at 36 weeks	—	5.8 NGT	6.9
10.8 (3.9 kg) from 12–14 to 34–36 weeks	—	3.9 (2.4) kg	7.0 (3.6) kg

TABLE J-9b Evidence on How the Increase in Tissue Deposition Associated with Pregnancy Influences, Effects, or Contributes to Energy Requirements: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Savard et al., 2021	32	Pregnant women, mostly White	Pregnancy	REE/TEE

NOTE: kcal = kilocalorie; REE = resting energy expenditure; TEE = total energy expenditure.

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
Increases in REE ranged from 0.5% to 18.3% (8 to 239 kcal) between early and midpregnancy, from 3.0% to 24.1% (45 to 327 kcal) between mid- and late pregnancy, and from 6.4% to 29.6% (93 to 416 kcal) between early and late pregnancy. The median increases in REE were 5.3% (72 kcal), 9.9% (153 kcal), and 18.0% (252 kcal) between early and mid-, mid- and late, and early and late pregnancy, respectively. Increases in TEE ranged from 4.0% to 17.7% (84 to 363 kcal) between early and midpregnancy, from 0.2% to 30.2% (5 to 694 kcal) between mid- and late pregnancy, and from 7.9% to 33.2% (179 to 682 kcal) between early and late pregnancy, respectively. The median increases in TEE were 6.2% (144 kcal), 7.1% (170 kcal), and 12.0% (290 kcal) between early and mid-, mid- and late, and early and late pregnancy, respectively.	REE and TEE increase during pregnancy, mainly from early to late and from mid- to late pregnancy. Great variability in the extent to which REE and TEE increase throughout pregnancy.	Huge variability. Inclusion of women with excessive gestational weight gain and sample with small number of overweight or obese women may have led to over-estimation of energy requirements.	—	Partially well done/ reported

TABLE J-10a Evidence on How the Increase in Tissue Deposition Associated with Lactation Influences, Effects, or Contributes to Energy Requirements: Nonsystematic Reviews

Author, Year	N	Age (SD)	BMI Status	Ethnicity
Pereira et al., 2019	52 and 49	32 y (4)	27.3 (5.6)	White
Thakkar et al., 2013	50	28–33 y		Asian
Nielsen et al., 2011	47 and in the end *n* = 30 with 26 EBF	33.7 y (4.3)	25.0 (3.9)	White
Nielsen et al., 2013	—	—	—	

NOTE: BF = breast feeding; BMI = body mass index; DLW = doubly labeled water; EBF = exclusively breast feeding; FFM = fat-free mass; FM = fat mass; g = gram; kcal/d = kilocalories/day; kg = kilogram; kJ = kilojoule; ml = milliliter; pp = postpartum; REE = resting energy expenditure; SD = standard deviation; TEE = total energy expenditure; y = years.

Weight Gain g/day (SD)	Findings
Negative 0.8 BMI units from 3 to 9 months pp	FFM gain of 0.4 g from 3 to 9 months pp FM loss of 2 g REE and TEE measured by whole-body calorimetry. REE increased significantly by 48 (108 kcal day) 3.2% at 3 months; breast milk volume 771 (261) g/d for breast milk energy output of 678 (230) kcal/day. At 9 months breast milk vol 530 (225) g/d for breast milk energy output of 465 (198) kcal/d. 41/52 and 28/49 were BF at 3 and 9 mo. TEE at 9 months 2,028 (286) kcal/d. No difference in TEE between lactating and nonlactating.
	Energy content of HM at 1 months was 65.92 (9.43) kcal/100 ml, at 3 months 70.24 (22.0). Energy content for milk produced for male infants was greater. Figure 1 shows significant difference at 3 months of 14.8 kcal/100 ml or 24% difference.
Mean weight at 15 days was male 6.72 (0.78) and female 6.30 (0.64); male 7.84 (0.91) and female 7.37 (0.75) at 25 weeks	Mean milk intake (DLW) 923 (SD = 122) g/day at 15 weeks and 997 (SD = 142) g/day at 25 weeks for all infants. For EBF 999 (SD = 146) g/day at 25 weeks. Milk energy content 2.72 (SD = 0.38) at 15 weeks, and 2.62 (SD = 0.40) kg/g at 25 weeks. No difference by sex. Energy intakes male 2,582 (SD = 362) and females 2,403 (SD = 215) kJ/day at 15 weeks and males 2,748 (SD = 480) and females 2,449 (SD = 312) kJ/day at 25 weeks. Significant difference by sex at 25 weeks (Table 2 in paper). However, milk and energy intake decreased from 15 weeks to 25 weeks (Table 3).
See Table 2 in Nielsen et al., 2013	Same as above (Nielsen et al., 2011) but now used DLW to measure TEE

TABLE J-10b Evidence on How the Increase in Tissue Deposition Associated with Lactation Influences, Effects, or Contributes to Energy Requirements: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Reilly et al., 2005	3–4 months, 33; 5–6 months, 6; 6 months, 5	3–4 months, 1,041; 5–6 months, 99; at 6 months, 72 mom–infant dyads; exclusively breast feeding	Not applicable	Milk transfer

NOTE: CI = confidence interval; d = day; g = gram; kcal = kilocalorie; kJ = kilojoule; SD = standard deviation; WHO = World Health Organization.

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
At 3–4 months: The weighted mean milk transfer was 779 g/d (SD = 40), and the unweighted mean was 796 g/d (SD = 48) (95% CI, 778; 812 g/day). At 5–6 months: Weighted mean milk transfer was 826 g/d (SD = 39). The unweighted mean was 816 g/d (SD = 42) (95% CI, 772; 860 g/d. At 6 months: Weighted mean milk transfer was 894 g/d (SD = 87) and unweighted mean transfer 883 g/d (SD = 89) (95% CI, 790; 975 g/d). Changes in breast milk transfers between 2 and 5 months from nine studies reported no marked increase in milk transfer over the periods of time measured, and most described the pattern of change in intake over time as a "plateau" in milk transfer after 3 months. The weighted mean metabolizable energy content of milk from 25 papers of 777 mom–infant pairs was 2.6 (SD = 0.2) kJ/g (equivalent to 0.62 kcal/g) (see Table 4 in Reilly et al., 2005).	Cross-sectional studies of milk transfer suggest that it typically varies between approximately 779 g/d at age 3–4 months (for which there was a great deal of evidence: 33 studies of 1,041 mother–infant pairs and approximately 894 g/d at age 6 months (for which evidence was limited: five studies with 72 possibly highly selected mother–infant pairs; longitudinal studies, in contrast, did not suggest any marked increase in milk transfer over time during the period of 3–6 months. The metabolizable energy content of breast milk is approximately 2.6 kJ/g. They speculate that using lower values for breast-milk energy content than the 0.67 to 0.68 kcal/g used in WHO reviews might alter the apparent adequacy of exclusive breastfeeding to 6 months of age.	Risk of bias was provided for included studies.	—	Partially well done/ reported

TABLE J-11 Evidence on the Calorie Intake Needed to Achieve Weight Loss (if Overweight), Weight Maintenance (for All Individuals), or Weight Gain (if Underweight): Systematic Reviews

Author, Year	Number of Studies	Sample Character-istics	Predictor or Intervention or Comparator	Primary Outcome
Heymsfield et al., 2007	10	150 obese subjects on low-calorie diet and patients with reduced obesity	Relationship between measured and predicted TEE among reduced obesity after long-term (≥ 26 weeks) weight loss treatment	TEE-DLW or indirect calorimeter

NOTES: DLW = doubly labeled water; kcal = kilocalorie; kg = kilogram; LCD = low-calorie diet; TEE = total energy expenditure.

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Mean difference between measured and predicted TEE for all reduced obesity subjects 20.1 kcal/day (–58, –155) % difference 1.3% (–1.7, –8.5). From the DLW studies—difference in –518 kcal/day. Reduction in energy intake of ~500 kcal/day had a weight loss of 30 kg.	Limited literature, but findings support that low patient adherence is the main basis for modest weight loss associated with LCD. Obese subjects have weight loss < 50% of expected for the degree of prescribed LCD energy deficit. TEE in the reduced obesity state is close to predicted in never obese subjects (1%).	—	—	Not well done/reported

TABLE J-12 Evidence on the Association Between Weight Change and Chronic Disease Outcomes: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Alharbi et al., 2021	2	715 community-dwelling males and females 65 y and older; not all from high-income countries	Intentional weight loss	All-cause mortality risk
Alharbi et al., 2021	23	1,210,116 community-dwelling males and females 65 y and older; not all from high-income countries	Weight gain	All-cause mortality risk

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 0.92 (0.54–1.54)	In this small sample of older adults, intentional weight loss was not associated with all-cause mortality. More research is needed on the effect of intentional weight loss on all-cause mortality or the reasons for intentional weight loss in older community-dwelling adults. Older, community-dwelling adults with very small sample size and no information on how weight loss was measured	good	Moderate heterogeneity p = .99; I^2 = 56%	Well done/ reported
RR (95% CI) = 1.10 (1.02–1.17)	No information on whether weight gains or losses were intentional Weight gain had a small, but significant association with all-cause mortality. In community-dwelling older adults, weight gains are associated with an increased risk of all-cause mortality relative to stable weight. Weight gain data were a mixture of measured and self-reported. Need research on reason for weight gain.	Most were good	Low heterogeneity p = .01; I^2 = 41%	Well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Alharbi et al., 2021	4	6,901 community-dwelling males and females 65 y and older; not all from high-income countries	Weight fluctuation	All-cause mortality risk
Capristo et al., 2021	17	39,875 males and females ≥ 18 y with overweight or obesity; not all from high-income countries	Weight loss associated with anti-obesity medications	All-cause mortality

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 1.66 (1.28–2.15)	No information on whether weight gains or losses were intentional A 63% increased risk of all-cause mortality with weight fluctuation compared to stable weight reference In community-dwelling older adults, weight fluctuations are associated with an increased risk of all-cause mortality relative to stable weight. Weight fluctuation data were a mixture of measured and self-reported. Need research on effect of intentional vs. unintentional weight fluctuations.	Most were good	No significant heterogeneity p = .31; I^2 = 14.6%	Well done/reported
OR (95% CI): 1.03 (0.87–1.21)	No significant reduction in risk of all-cause mortality with weight-lowering drugs compared with placebo or no treatment. There was a weak, but statistically significant, linear association between all-cause mortality and magnitude of weight loss (ß = 0.0007, p = .045). A weight loss of 20 kg would lower mortality by 1.4% and a 30-kg weight loss by 2.1%.	Suboptimal quality	No significant heterogeneity I^2 = 0%; p = 1.0	Not well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Capristo et al., 2021 (continued)				
Capristo et al., 2021	8	28,657 males and females ≥ 18 y with overweight or obesity; not all from high-income countries	Weight loss associated with antiobesity medications	Cardio-vascular mortality
Capristo et al., 2021	7	30,404 males and females ≥ 18 y with overweight or obesity; not all from high-income countries	Weight loss associated with anti-obesity medications	Myocardial infarction

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
	Although unable to demonstrate a superiority of anti-obesity medications over placebo, meta-regression showed that even a small weight reduction tends to reduce all-cause mortality in obesity. The health status of participants is not described.			
OR (95% CI): 0.92 (0.72–1.18)	No significant decrease in the risk of CVD death with antiobesity drugs Linear association between CVD mortality and magnitude of weight loss was not significant. Unable to demonstrate an effect of weight-loss medications on CVD mortality in trials with an average of 52 weeks of follow-up. Unclear as to the health status of participants	Suboptimal quality	No significant heterogeneity $I^2 = 0\%$; $p = .79$	Not well done/ reported
OR (95% CI): 1.01 (0.86–1.19	No significant decrease in the risk of myocardial infarction with anti-obesity drugs. Unable to demonstrate an effect of weight-loss medications on myocardial infarction in trials with an average of 52 weeks follow-up. Unclear as to the health status of participants or if these were incidence cases	Suboptimal quality	No heterogeneity $I^2 = 0\%$, $t^2 = 0$, $p = .87$	Not well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Capristo et al., 2021	4	21,584 males and females ≥ 18 y with overweight or obesity; not all from high-income countries	Weight loss associated with anti-obesity medications	Stroke
Chan et al., 2019	8	1,373 females ≥ 18 y; underweight women (BMI < 18.5) excluded; not all from high-income countries	Adult weight loss of unknown intention	Premenopausal breast cancer
Chan et al., 2019	14	8,283 females ≥ 18 y; underweight women (BMI < 18.5) excluded; not all from high-income countries	Adult weight loss of unknown intention	Postmenopausal breast cancer

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
OR (95% CI): 0.93 (0.72–1.20)	Unable to demonstrate effect of weight loss medications on stroke Unclear as to the health status of participants or if these were incidence cases	Suboptimal quality	No heterogeneity I^2 = 0%, t^2 = 0, p = .49	Not well done/ reported
RR (95% CI): 0.85 (0.74–0.99)	Inverse associations for premenopausal breast cancers when comparing any weight loss of unknown intention from age 18 y to study baseline with stable weight The results were not robust and require further confirmation.	Most studies considered average to good quality. Higher or lower RoB studies on average did not find statistically different associations in the subgroup meta-analyses.	I^2 = 0%, p = .93	Not well done/ reported
RR (95% CI): 0.90 (0.81–0.99)	Inverse associations for postmenopausal breast cancers when comparing any weight loss of unknown intention from age 18 y to study baseline with stable weight. The results were not robust and require further confirmation.	Most studies considered average to good quality. Higher or lower RoB studies on average did not find statistically different associations in the subgroup meta-analyses.	I^2 =24%, p heterogeneity = 0.20	Not well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Chan et al., 2019	9	Females ≥ 18 y; underweight women (BMI < 18.5) excluded; not all from high-income countries	Adult weight gain per 5 kg (of unknown intention)	Premenopausal breast cancer
Chan et al., 2019	16	Females ≥ 18 y; underweight women (BMI < 18.5) excluded; not all from high-income countries	Adult weight gain per 5 kg (of unknown intention)	Postmenopausal breast cancer

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 1.00 (0.97–1.03)	No association of weight gain and breast cancer in premenopausal women	Most studies considered average to good quality. Higher or lower RoB studies on average did not find statistically different associations in the subgroup meta-analyses.	I^2 = 20.7%, *p* = .265	Not well done/reported
RR (95% CI) = 1.07 (1.11–1.23)	Positive association of weight gain and breast cancer in postmenopausal women	Most studies considered average to good quality. Higher or lower RoB studies on average did not find statistically different associations in the subgroup meta-analyses.	I^2 = 64%; *p* heterogeneity ≤ .001	Not well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Hao et al., 2021	19	862,177 females ≥ 19 y; American, European, Australia, Asian (Japanese, Chinese)	Highest adult weight gain since early adulthood for both whole adulthood and hormone-changed menopause stages	Onset of breast cancer or total cancers

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
Highest vs. lowest weight gain and premenopausal risk: RR = 1.00 (95% CI, 0.83, 1.21); postmenopausal risk: RR = 1.55 (95% CI, 1.40, 1.71). Dose–response: RR per 5-mg weight gain: 1.08 (95% CI, 1.07, 1.09). Weight gain since menopause: RR = 1.59 (95% CI, 1.23, 2.05).	Weight gain in Asian women had a much stronger effect (34%) than in other countries. No significant findings among premenopausal women: RR, 1.00; 95% CI, 0.83–1.21 Dose–response analysis confirmed a significant increased risk of 8% of developing postmenopausal breast cancer with each 5-kg increment in adult weight gain for Western women, but about a 34% stronger risk in Asian women. No significant finding among premenopausal women. Higher weight gain since menopause associated with increased postmenopausal breast cancer risk based on comparison of highest vs. lowest adult weight gain. For postmenopausal women, there was a significant effect of weight gain since menopause on breast cancer risk. The effect is strongest in Asian women. No effect of weight gain on breast cancer risk in premenopausal women. The majority of participants came from Europe, United States, United Kingdom, Canada, Australia. Only a small minority were from China or Japan.	No data	Highest vs. lowest weight gain in premenopausal women: I^2 = 24.9%. Postmenopausal women I^2 = 47.2%. Dose–response: postmenopausal I^2 = 69.4%.	Partially well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Jayedi et al., 2018	5	134,247 males and females; general population > 18 y with > 1 y follow-up; high-income countries	Weight gain equal to a 1-unit increment in BMI (both self-reported and measured weights)	Hypertension incidence

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
There was a linear association between weight gain and risk of hypertension (*p* non-linearity = 0.58)	There was a linear association between weight gain and risk of hypertension (*p* non-linearity = 0.58) Adjustment for baseline blood pressure attenuated the associations, but results remained significant, indicating that adiposity increases the risk of hypertension independently of baseline blood pressure. Greater risk in self-reported subgroup compared with measured. Preventing weight gain in adults is a useful approach for reducing the risk of hypertension. The study provided evidence of the role of weight gain in hypertension risk. One limitation was the failure of included studies to control for salt intake or renal function. Some evidence of publication bias.	No data	I^2 = 77.8%. *p* heterogeneity = 0.001	Well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Jayedi et al., 2020	Of 11 studies with data on CVD mortality, 5 had data on participants without pre-existing CVD	< 505,802 males and females ≥ 18 y reporting unintended weight gain during adulthood or before assessment; Europe (13), United States (8), Asia (2), Australia (1), Middle East (1)	Weight gain during adulthood	CVD mortality in persons without pre-existing CVD
Jayedi et al., 2020	2	118,140 males and females ≥ 18 y reporting unintended weight gain during adulthood or before assessment; Europe (13), United States (8), Asia (2), Australia (1), Middle East (1)	Weight gain during adulthood	CVD incidence

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 1.14 (1.02 to 1.26) for a 5-kg increment in body weight	A nonlinear dose–response analysis indicated that the risk of CVD mortality did not change materially with weight gain of 0 to 5 kg and then increased sharply at weight gain of > 6 kg. Measuring weight gain during adulthood may be better than static, cross-sectional assessment of weight because it considers trend over time, and thus, can be used as a supplementary approach to predict CVD. Adult weight gain could increase the risk of CVD incidence and mortality. Slightly more than half of the studies relied on self-reported weight gain, which could have attenuated relationships.	Out of a possible score of 9, 1/3 of the studies were rated as 7 and 2/3 as 8.	$I^2 = 84\%$, p heterogeneity = < 0.001; p heterogeneity between subgroups = 0.15	Partially well done/ reported
RR (95% CI) = 1.12 (1.10, 1.13) for a 5-kg increment in body weight	In five studies in which participants with preexisting CVD were excluded, the RR (95% CI) = 1.14 (1.02 to 1.26). $I^2 = 84\%$ ($p < .001$) and between group heterogeneity = 0.15. Measuring weight gain during adulthood may be better than a static, cross-sectional measurement of weight (e.g., BMI) for predicting CVD risk. Adult weight gain may be associated with a higher risk of CVD.	Out of a possible score of 9, 1/3 of the studies were rated as 7 and 2/3 as 8.	$I^2 = 6\%$, p heterogeneity = 0.30	Partially well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Karahalios et al., 2017	18	Healthy adults measured between middle and older age No data on number of participants	Weight at baseline and follow-up based on measured weight (subgroup analysis)	All-cause mortality

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
No data	Used results from a subgroup of participants whose weights were based on measured values rather on the full sample that combined measured and self-reported weights. Weight gain in middle-aged to older adults is associated with muscle-mass decreases and fat-mass increases, with the largest increase in visceral and abdominal fat. Weight gain from middle to older adulthood was associated with a slightly increased risk of all-cause mortality. Studies using self-reported measures of weight at baseline and follow-up had higher HRs than studies with measured weight. None of the participants were underweight at baseline.	No data	I^2 = 64.4%, tau^2 = 0.16. Ratio of HRs = 1.00	Partially well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Karahalios et al., 2017	11	Healthy adults measured between middle and older age No data on number of participants	Measured weights at baseline and follow-up. Largest weight gain from baseline to follow-up. Included both intentional and unintentional weight gain. Excluded studies that investigated weight gain from early adulthood to middle age; included studies of weight gain from middle age to older age.	CVD mortality
Karahalios et al., 2017	2	Healthy adults measured between middle and older age No data on number of participants	Intentional weight loss (measured and self-reported)	All-cause mortality

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 1.14 (0.97, 1.35)	Studies that used self-reported measures of weight gain had higher HRs (HR = 1.41, 95% CI = 0.97, 2.05. Studies with normal weight or overweight/obese participants gave similar HRs to studies that combined all participants. The effect of baseline weight on association is unknown. Weight gain in midlife is associated with increased risk of CVD mortality.	No data	I^2 = 58.2%, tau^2 = 0.029. Ratio of HRs = 1.00 The time between weight measurements (i.e., > 10 y or < 10 y) explained much of the heterogeneity. Studies with > 10 y between weight measurements had higher HRs than studies with < 10 y	Partially well done/reported
HR = 1.44 (95% CI = 1.03, 2.00)	Results from weight-loss studies with measured weights and including both intentional and unintentional weight loss were similar: HR = 1.40 (95% CI = 1.14, 1.71); Unintentional weight loss might reflect an underlying disease, resulting in excess mortality. Only two studies had data on intentional weight loss.	No data	No data	Partially well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
LeBlanc et al., 2018	9	Males and females ≥ 19 y; high-income countries Included studies with ≥ 12 months follow-up and participants ≥ 18 y with above normal weight. Excluded studies with participants with chronic diseases or secondary causes of obesity.	Behavior-based weight loss	Diabetes incidence in prediabetic participants

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI): 0.67 (0.51 to 0.89)	Weight loss interventions associated with a decreased risk of type 2 diabetes in prediabetic participants up to 36 months of follow-up. Behavior-based weight-loss interventions were associated with more weight loss than controls. Weight loss maintenance interventions were associated with less weight regain than control conditions over 12 to 18 months Behavior-based weight loss interventions were associated with more weight loss and a lower risk of developing diabetes than control conditions. Weight-loss medications were associated with higher rates of harms than behavior-based interventions. Infrequent reporting of CVD, cancer, and all-cause mortality precluded summarizing data for these outcomes.	—	$I^2 = 49.2\%$, $p = .46$. The consistency across interventions and subgroups suggests that benefits are likely dependent on individual, social, and environmental factors more than intervention characteristics.	Partially well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Ma et al., 2017	24	15,176 males and females age ≥ 19 y with obesity	Dietary weight loss ± physical activity. All but 1 of the diets were low fat. Follow-up for ≥ 1 y.	New CVD events
Ma et al., 2017	19	6,330 males and females age ≥ 19 y with obesity	Dietary weight loss ± physical activity. All but 1 of the diets were low fat. Follow-up for ≥ 1 y.	New cancers

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 0.93 (0.83, 1.04	Similar results when using ACC/AHA definitions. "New CVD events" was a secondary outcome. Predominantly in middle-aged adults, the authors were unable to show effects of weight loss on new CVD events. There were fewer trials and much uncertainty for this outcome. Because all but one study used a low-fat, weight-reducing diet, the results are relevant only to this cause of weight loss.	—	$I^2 = 0\%$, $p =$ .829	Partially well done/ reported
RR (95% CI) = 0.92 (0.63, 1.36)	"New cancers" was a secondary outcome. Predominantly in middle-aged adults, the authors were unable to show effects of weight loss on new cancer events. There were fewer trials and much uncertainty for this outcome. Because all but one study used a low-fat, weight-reducing diet, the results are relevant only to this cause of weight loss.	—	$I^2 = 0\%$; $p =$ .992.	Partially well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Ma et al., 2017	34	Males and females age ≥ 19 y with obesity	Dietary weight loss ± physical activity. All but 1 of the diets were low-fat. Follow-up for ≥ 1 y.	All-cause mortality
Sun et al., 2021	6 studies in meta-analysis	128,164 males and females, from childhood to adulthood; mixed race/ethnicity; not all from high-income countries Age at baseline weight assessment < 20 y	Those with (1) normal weight in childhood and overweight/obese in adulthood; (2) overweight/obese in childhood and adulthood; (3) overweight/obese in childhood and normal weight in adulthood	T2D

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR (95% CI) = 0.82 (0.71, 0.95)	Predominantly in middle-aged adults, weight-loss diets, usually low in fat and saturated fat, with or without exercise advice or programs, may reduce premature all-cause mortality in adults with obesity. Because all but one study used a low-fat, weight-reducing diet, the results are relevant only to this cause of weight loss.	—	$I^2 = 0\%$. $p = .945$	Partially well done/ reported
Compared to normal weight in childhood and adulthood, ORs (95% CI) of adult T2D were: (1) 3.40 (2.71 to 4.25) for normal child weight but overweight/ obese adult weight; (2) 3.94 (3.05 to 5.08) for overweight/ obese in childhood and adulthood; (3) 1.37 (1.10 to 1.70) for overweight/ obese in childhood but normal weight in adulthood	Those who developed excess weight in adulthood or were persistently overweight/obese in childhood and adulthood had increased risk of T2D. Those with excess child weight but normal adult weight had a much reduced increase in risk. NOTE: They also assessed a number of other CVD risk factors, including dyslipidemia, nonalcoholic fatty liver disease, metabolic syndrome, inflammation, left ventricular hypertrophy, and subclinical CVD markers. All showed increased OR in the incident and persistent obesity groups, and most were NS for resolved obesity.	Study quality ranged from 6 to 8 out of 9 (moderate to high quality)	Heterogeneity assessed. After subgroup analyses by child age (< 11 and > 11 years) and adult age (< 30 and > 30 years); definition of childhood overweight and obesity (U.S. CDC and international BMI percentile); measured vs. self-reported weight and height, the heterogeneity disappeared.	Partially or not well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Sun et al., 2021	4 studies in meta-analysis (vs. 10 in review)	30,309 males and females, from childhood to adulthood; mixed race/ethnicity; not all from high-income countries Age at baseline weight assessment < 20 y	Those with (1) normal weight in childhood and overweight/obese in adulthood; (2) overweight/obese in childhood and adulthood; (3) overweight/obese in childhood and normal weight in adulthood	Hypertension

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Compared to normal weight in childhood and adulthood, ORs (95% CI) of adult hypertension were: (1) 2.69 (2.07 to 3.49) for normal child weight but overweight/obese adult weight; (2) 3.49 (2.21 to 5.05) for overweight/obese in childhood and adulthood; (3) 1.25 (0.73 to 2.13) for overweight/obese in childhood but normal weight in adulthood	Incident and persistent overweight/obesity are associated with increased risk of adult hypertension. Resolved obesity is not.	Study quality ranged from 6 to 8 out of 9 (moderate to high quality)	Heterogeneity assessed. After subgroup analyses by child age (< 11 and > 11 years) and adult age (< 30 and > 30 years); definition of childhood overweight and obesity; measured vs. self-reported weight and height, the heterogeneity disappeared.	Partially or not well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Sun et al., 2021	4 studies in meta-analysis	87,556 males and females, from childhood to adulthood; mixed race/ethnicity; not all from high-income countries Age at baseline weight assessment < 20 y	Those with (1) normal weight in childhood and overweight/obese in adulthood; (2) overweight/obese in childhood and adulthood; (3) overweight/obese in childhood and normal weight in adulthood	Adult cardiovascular disease (CHD, CVD, stroke, heart failure)

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Compared to normal weight in childhood and adulthood, ORs (95% CI) of adult CVD were: (1) 2.76 (1.79 to 4.27) for normal child weight but overweight/ obese adult weight (2) 3.04 (1.69–5.46) for overweight/ obese in childhood and adulthood; (3) 1.22 (0.92–1.62) for overweight/ obese in childhood but normal weight in adulthood	Incident and persistent overweight/obesity are associated with increased risk of adult CVD. Resolved obesity is not.	—	Heterogeneity assessed. After subgroup analyses by child age (< 11 and > 11 years) and adult age (< 30 and > 30 years); definition of childhood overweight and obesity; measured vs. self-reported weight and height, the heterogeneity disappeared.	Partially or not well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Wang et al., 2021	20	38,141 males and females ≥ 19 y; from United States, Europe, Nigeria, Australia, South Korea	Weight loss	Diagnosis of dementia
Zhang et al., 2019	15	623,973 males and females ≥ 19 y; from United States, South Korea, Australia, Germany, UK	Weight fluctuation episodes	All-cause mortality

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR = 1.26, 95% CI 1.15 to 1.38	Subgroup analysis by baseline BMI identified that weight loss in normal weight participants had similar dementia risk (1.21, 95% CI 1.06–1.38) to weight loss in overweight/obese individuals (1.22, 1.11–1.34). Weight loss may be associated with increased risk of dementia. Maintaining stable weight may help prevent dementia. Information was not available on whether weight loss was intentional or not.	12 studies were high quality (score of 7–9) and 8 were medium quality (4–6)	Subgroup analyses conducted (degree of weight loss, dementia subtype, diagnostic criteria for dementia, country, sex, age, baseline BMI, baseline health status, duration of follow-up, and adjusted factors). In most cases, results were consistent among subgroups.	Well done/reported
Overall HR for group with greatest weight fluctuation (vs. group with most stable weight) was 1.45 (95% CI 1.29 to 1.63)	Weight fluctuation might be associated with an increased risk of all-cause mortality.	Newcastle scores ranged from 5 to 9 (moderate to high quality)	Heterogeneity assessed by meta-regression, sensitivity analyses, and stratified analyses according to prespecified study characteristics. Overall conclusion was not changed.	Partially well done/reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Zou et al., 2019	20	341,395 males and females ≥ 19 y	Weight fluctuation (studies varied in how this was measured)	All-cause mortality
Zou et al., 2019	11	245,109 males and females ≥ 19 y	Weight fluctuation (studies varied in how this was measured)	CVD mortality
Zou et al., 2019	6	172,709 males and females ≥ 19 y	Weight fluctuation (studies varied in how this was measured)	Cancer mortality
Zou et al., 2019	5	122,920 males and females ≥ 19 y	Weight fluctuation (studies varied in how this was measured)	CVD morbidity

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR = 1.41 (95% CI 1.27, 1.57)	Relationship between weight fluctuation and all-cause mortality did not differ by BMI or age or by how weight fluctuation was measured (continuous or categorical) Body-weight fluctuation is associated with higher all-cause mortality. Future study needed to determine causal links. Studies included weight fluctuation measured either as categorical (episodes of a given magnitude) or continuous (e.g., intrapersonal variation of weight). Most studies did not indicate if weight fluctuation was intentional or not.	Most studies were high quality	Analysis of heterogeneity was significant. Contributing factors included study location, duration, quality, weight ascertainment measured or self-reported, adjustment for physical activity and energy intake.	Partially well done/ reported
RR = 1.36 (95% CI 1.22, 1.52)	Relationship between weight fluctuation and CVD mortality was observed in those with normal weight and overweight but not with obesity or by how weight fluctuation was measured (continuous or categorical)	11 of 11 studies were high quality	Heterogeneity NS	Partially well done/ reported
RR = 1.01 (95% CI, 0.90, 1.13)	Body weight fluctuation is NOT associated with cancer mortality.	6 of 6 studies were high quality	Heterogeneity NS	Partially well done/ reported
RR = 1.49 (95% CI, 1.26, 1.76)	Body weight fluctuation is associated with CVD	3 of 5 studies were high quality	Significant. Appeared to be affected by method of weight ascertainment	Partially well done/ reported

continued

TABLE J-12 Continued

Author, Year	Number of Studies	Sample Characteristics	Predictor or Intervention or Comparator	Primary Outcome
Zou et al., 2019	4	144,256 males and females ≥ 19 y	Weight fluctuation (studies varied in how this was measured)	Hypertension

NOTE: ACC = American College of Cardiology; AHA = American Heart Association; BMI = body mass index; CHD = coronary heart disease; CI = confidence interval; CVD = cardiovascular disease; HR = hazard ratio; kg = kilogram; m = meter; NS = non-significant; OR = odds ratio; RoB = risk of bias; RR = relative risk; T2D = type 2 diabetes; y = year.

TABLE J-13 Evidence on the Association Between BMI and Chronic Disease, Including All-Cause Mortality: Systematic Reviews and Observational Studies

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Azizpour et al., 2018	16	8,397 including 3,577 cases	1–18 y	Females and males	≥ 25.0 and ≥ 30.0
Sharma et al., 2019	52	1,553,683	5–13 y	Females and males	≥ 85th percentile
Hidayat et al., 2019	6	13,510 cases	Pregnancy	Females	≥ 25.0
Xiao et al., 2021	103	1,826,454 including 120,696 cases	Pre-pregnancy	Females	≥ 25.0

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
RR = 1.35, 95% CI, 1.14, 1.61	Body weight fluctuation is associated with hypertension	Not reported	Heterogeneity NS	Partially well done/ reported

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
Asthma	Overweight 1.64 (95% CI 1.13–2.38); obese 1.92 (1.39–2.65)	Risk for asthma in children and adolescents who are overweight or obese is 64–92% higher compared to underweight/normal weight.	p = 0.312; P = 0.09	—
Child/ adolescent prediabetes, HTN, NAFLD	Prediabetes: 1.4 (1.2–1.6); HTN: 4.0 (2.8–5.7); NAFLD: 26.1 (9.4–72.2)	Children and adolescents (age 5–13) with overweight or obesity (≥ 85th percentile) are 1.4 times more likely to have prediabetes; those with obesity are 4.4 times more likely to have high blood pressure and 26.1 times more likely to have NAFLD.	—	Partially well done/ reported
Child-onset T1DM	Overweight 1.09 (1.03–1.15); obese 1.25 (1.16–1.34)	Each 5-unit increase in maternal BMI associated with 10% increased risk for child-onset T1DM. Association was nonlinear, with steeper increase in risk at BMI ≥ 26.0	p = 0.23	—
Gestational diabetes	2.64 (1.56–4.45)	Prepregnancy overweight or obesity increases risk 2.64-fold for having gestational diabetes.	—	Partially well done/ reported

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Ibe and Smith, 2014	BRFSS (Behavioral Risk Factor Surveillance System)	1,168,418	18–64	Females	≥ 25.0
Jayedi et al., 2022	182	5,585,850, including 228,695 cases	> 18	Females and males	> 20
Khadra et al., 2019	11	60,118	19–50	Females and males	≥ 25.0
Larsson et al., 2021	47	218,792	> 18	Females and males	≥ 25.0
Yu et al., 2022	82	2,690,000	> 18	Females and males	≥ 25.0
Jayedi et al., 2018	50	2,255,067, including 190,320 cases	> 18	Females and males	> 20
Zhou et al., 2018	57	830,685, including 125,071 cases	> 18	Females and males	□
Rexrode et al., 2001	Physicians Health Study	16,164, including 552 cases	40–84	Males	≥ 27.6

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
T2DM	3.57 (3.52–3.63)	Adjusting for age, race, physical activity, and year of survey response, results indicate a 3.5-fold increase in diabetes in females with BMI > 25.	—	—
T2DM	1.72 (1.65–1.81)	Each 5-unit increase in BMI above 20.0 associated with 72% increased risk for T2DM, with steep upward curve at BMI > 25 in younger adults.	—	—
T2DM	1.38 (1.27–1.50)	Sarcopenic obesity is associated with a 38% increased risk for T2DM compared to nonsarcopenic obesity.	—	—
T2DM	2.03 (1.88–2.19)	Mendelian randomization (genetically predicted) studies show high adult BMI is a causal risk factor for T2DM, with a 2-fold increased risk for T2DM when BMI ≥ 25.	—	—
Prediabetes, T2DM	Prediabetes overweight and obesity: 1.24 (1.19–1.28); T2DM overweight: 2.24 (1.95–2.56); obese: 4.56 (3.69–5.64)	Overweight and obesity are associated with a 24% increased risk for prediabetes. Overweight is associated with a 2-fold increased risk and obesity a 4.5-fold increased risk for T2DM.	—	Partially well done/reported
HTN	1.49 (1.41–1.58)	Each 5-unit increase in BMI above 20.0 is associated with 49% increased risk for HTN.	0.0001	—
HTN	BMI 18.5: 1.27 (1.20–1.35), BMI 25.0: 2.07 (1.34–2.46), BMI 30: 3.13 (2.49–3.93)	Risk for HTN increases at least 50% for every 5-unit increase in BMI.	—	Partially well done/reported
CHD	1.73 (1.29–2.32)	Males with BMI ≥ 27.6 have a 73% increased risk for a CHD event.	—	—

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Kim et al., 2000	Framingham Heart Study	1,882	30–62	Males	≥ 23.8
Kim et al., 2000	Framingham Heart Study	2,373	30–62	Females	≥ 27.6
Liu et al., 2018a	43	4,432,475, including 102,466 cases	> 18	Females and males	> 23.5
Dugani et al., 2021	16	12,700,000	> 18	Females (18–65) and males (18–55)	≥ 25.0 and ≥ 30.0
Meigs et al., 2006	Community Longitudinal Study	2,902	> 18	Females and males	≥ 25.0
Darbandi et al., 2020	38	137,256	> 18	Females and males	≥ 30.0
Kim et al., 2021	77	30,000,000	> 18	Females and males	> 20
Church et al., 2005	Aerobics Center Longitudinal Study	2,316	> 20	Males with T2DM	≥ 25.0
Jarvis et al., 2020	14	1,930,000, including 49,451 cases	> 18	Females and males	> 30.0

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
CHD	1.28 (1.00–1.65)	In males, the relative risk for CHD is 28% at BMI ≥ 23.8, 45% at BMI ≥ 25.9 and 53% at BMI ≥ 28.2	—	—
CHD	1.56 (1.16–2.08)	In females with BMI ≥ 27.6, there is a 56% increased risk for developing CHD.	—	—
Stroke	1.10 (1.06–1.13)	Risk of stroke increases by 10% for every 5-unit increase in BMI > 23.5, and is greater for males than for females.	$p = 0.06$	Well done/ reported
Premature MI	Males 1.94 (1.47–2.56); females 1.28 (0.95–1.73)	Males in overweight or obese BMI categories have almost a 2-fold increased risk for premature MI.	—	—
CVD	Overweight: 3.01 (1.68–5.41)	Adults with overweight/ obesity have a 3-fold increased risk for CVD.	—	—
CVD	BMI: AUC 0.66 (0.63–0.69); WC: AUC 0.69 (0.64–0.74); WHR: AUC 0.69 (0.66–0.73) males, 0.71 (0.68 = 0.73) females	BMI, WC, and WHR have moderate power to identify risk for CVD. In adults, WC and WHR predict CVD better than BMI.	$p < 0.001$	—
CVD	1.10 (1.01–1.210 for hemorrhagic stroke; 1.49 (1.40–1.60) for HTN	Mendelian randomization (genetically predicted) studies show high BMI is a causal risk factor for CVD outcomes; each 5-unit increase in BMI increases risk for CVD events.	—	—
CVD mortality	2.70 (1.40–5.10)	Overweight and obese males with diabetes have similar 2.7-fold increased risk for CVD-mortality.	—	—
NAFLD	1.20 (1.12–1.28)	BMI > 30 is associated with 20% increased risk for severe liver disease.	—	—

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Campbell et al., 2016	14	1,570,000, including 2,162 cases	> 18	Females and males	≥ 25.0
Sohn et al., 2021	28	8,135,906	> 18	Females and males	≥ 25.0
Byun et al., 2022	37	1,849,875, including 39,733 cases	≤ 30	Females	13.2–32.5
Byun et al., 2022	10	662,779, including 4,539 cases	≤ 30	Females	15.3–32.5
Byun et al., 2022	6	496,391, including 2,692 cases	≤ 30	Females	14.6–32.5
Fang et al., 2018	325	1,525,052	> 18	Females and males	> 20.0

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
Hepato-cellular carcinoma	1.21 (1.09–1.35)	Compared with normal weight BMI, persons with overweight, class I obesity, class II obesity, and class III obesity were associated with 21%, 87%, 142%, and 116%, respectively, increased risk of liver cancer.	—	—
Hepato-cellular carcinoma	1.69 (1.50–1.90)	Risk for liver cancer increases in a BMI-dependent manner with a 36% increased risk for BMI > 25, 77% increased risk for BMI > 30, a 3-fold increased risk for BMI > 35 (and a 70% increased risk overall for BMI ≥ 25.0).	—	Well done/ reported
Breast cancer (pre-menopausal)	0.84 (0.81–0.87)	Each 5-unit increase in early-life BMI is associated with 16% reduced premenopausal breast cancer risk.	$p < 0.001$	—
Endo-metrial cancer	1.40 (1.25–1.57)	Each 5-unit increase in early-life (age ≤ 25 y) BMI associated with 1.4-fold increased endometrial cancer risk.	$p < 0.001$	—
Ovarian cancer	1.15 (1.07–1.23)	Each 5-unit increase in early-life (age ≤ 25 y) BMI is associated with 15% increased risk for ovarian cancer	$p < 0.001$	—
Cancer (23 tissue types)	Endometrial: 1.48	Every 5-unit increase in BMI is associated with increased risk for 18 types of tissue cancers. The strongest positive association is between BMI and endometrial cancer (RR = 1.48). BMI was negatively associated with the risk of oral cavity, lung, and premenopausal breast cancers.	—	—

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Gao et al., 2019	27	28,784,269, including 127,161 cases	> 18	Females and males	≥ 25.0
Gu et al., 2022	52	279,499, including 51,704 cases	> 18	Males	≥ 25.0
Hidayat et al., 2018a	56	56,744	≤ 30	Females and males	≥ 20.0
Hidayat et al., 2018b	22	7,000,000, including 20,000 cases	> 18	Females and males	≥ 20.0
Li et al., 2016	12	5,902 cases	> 18	Females and males	≥ 25.0
O'Sullivan et al., 2022	20	47,692 cases	≤ 50	Females and males	≥ 30.0

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
Lung cancer	BMI: 0.77 (0.72–0.82); WC: 1.24 (1.13–1.35)	BMI is inversely associated with lung cancer risk. When controlling for BMI, high waist circumference associates with lung cancer risk.	p = 0.005	—
Prostate cancer	0.99 (0.99–1.00)	Higher BMI associated with 1% decreased risk for localized prostate cancer.	—	—
Cancer (8 types)	□	Each 5-unit increase in early-life (≤ 30 y) BMI is associated with 1.88-fold increased risk for esophageal cancer, 1.31-fold increased risk for liver cancer, 1.17-fold increased risk for pancreatic cancer, 1.59-fold increased risk for gastric cancer, 1.22-fold for kidney cancer, and 1.45-fold increased risk for endometrial cancer.	—	—
Non-Hodgkin's lymphoma	1.13 (1.06–1.20)	Each 5-unit increase in BMI is associated with 6% increased risk for NHL, with no difference by sex. Further, each 5-unit increase in BMI in early adulthood (18–21 y) is associated with 11% increased risk for NHL.	—	—
Gallbladder cancer	Overweight: 1.10 (0.98–1.23); Obese 1.58 (1.43–1.75)	The pooled risk for gallbladder cancer at BMI ≥ 25 for overweight is 10% and obesity 58%, and risk increases by 4% for each 1-unit increase in BMI.	—	—
Colorectal cancer—early onset	Obese: 1.54 (1.01 – 2.35)	Obesity (BMI ≥ 30) is associated with a 54% increased risk of early onset (≤ 50 y) colorectal cancer, with males at higher risk than females.	—	Well done/ reported

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Li et al., 2021	6	8,150,473, including 11,299 cases	≤ 55	Females and males	≥ 25.0
Liu et al., 2018b	24	8,953,478, including 15,535 cases	> 18	Females and males	> 20
Youssef et al., 2021	31	24,489,477, including 86,097 cases	> 18	Females and males	< 18.5, ≥ 25.0
Jiang et al., 2019	9	96,213	≥ 65	Females and males	> 28
Mortensen et al., 2021	35	1,508,366	> 50	Females and males	< 18.5
Jiang et al., 2019	37	320,594	≥ 65	Females and males	< 23 and > 33.0

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
Colorectal cancer—early onset	Overweight 1.32 (1.19–1.47); obese 1.88 (1.40–2.54)	Overweight and obesity (BMI ≥ 25) are associated with a 42% increased risk of early-onset (age ≤ 55) colorectal cancer.	p = 0.60	—
Kidney cancer	Overweight: RR 1.35 (1.27–1.43); obese RR 1.76 (1.61–1.91)	Risk of kidney cancer increases 6% for every 1-unit increase in BMI > 20.	—	Well done/reported
Thyroid cancer	Underweight: 0.68 (0.65–0.72); overweight: 1.26 (1.24–1.28); obese: 1.50 (1.45–1.55)	Overweight and obesity are associated with a 26% and 50% increased risk of thyroid cancer, with risk greater in females than males. Having an underweight BMI decreases risk by 32%.	—	Not well done/reported
Disability	1.19 (1.01–1.40)	BMI 24.0–28.0 decreases risk by 4% for disability in adults age ≥ 65 years, but BMI > 28 increases disability risk by 19%.	—	—
Fragility hip fracture	2.83 (1.82–4.39)	BMI < 18.5 is associated with almost a 3-fold increased risk for fragility hip fracture, whereas BMI > 30 may be protective.		Partially well done/reported
All-cause mortality	BMI < 18.5: 1.69 (1.57–1.83); BMI 18.5–22.9: 1.17 (1.12–1.22); BMI 23.0–27.9: 0.91 (0.88–0.94); BMI 28.0–32.9: 0.98 (0.94–1.03); BMI > 33.0: 1.32 (1.15–1.51)	BMI < 23.0 and > 33.0 increase risk for all-cause mortality in adults ≥ 65 years	—	—

continued

TABLE J-13 Continued

Author, Year	Number of Studies	Number of Participants	Age or Life Stage	Sex	BMI Cut Point for Risk
Kitahara et al., 2014	20	9,564	> 18	Females and males	Class III obesity

NOTE: AUC = area under the curve; BMI = body mass index; BRFSS = Behavioral Risk Factor Surveillance System; CHD = coronary heart disease; CVD = cardiovascular disease; HTN = hypertension; kg = kilogram; m = meter; MI = myocardial infarction; NAFLD = non-alcoholic fatty liver disease; RR = relative risk; NHL = non-Hodgkin's lymphoma; T1DM = type 1 diabetes mellitus; T2DM = type 2 diabetes mellitus; WC = waist circumference; WHR = waist–hip ratio; y = year.

TABLE J-14 Evidence on the Degree of Systematic Bias or Random Error of Energy Intake as Assessed by Self-Report Compared to Doubly Labeled Water Studies: Systematic Reviews

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Burrows et al., 2019	36	2,834 male and female adults, including pregnant women; not all high-income countries	Food record / TEE from DLW	EI-TEE
Burrows et al., 2019	24	3,295 male and female adults, including pregnant women; not all high-income countries	24-hour recall / TEE from DLW	EI-TEE
Burrows et al., 2019	21	2,997 male and female adults, including pregnant women; not all high-income countries	FFQ / TEE from DLW	EI-TEE
Burrows et al., 2019	5	71 male and female adults, including pregnant women; not all high-income countries	Diet history / TEE from DLW	EI-TEE

Primary Outcome	Quantitative Finding(s)	Clinical Interpretation	Risk of Bias	Overall AMSTAR2 Rating
All-cause mortality	BMI 40–59: 1.40 (1.31–1.51)	Adults with BMI 40–49 have a 2.3- to 3.3-fold increased risk for death, those with BMI 50–59 have a 3.5 to 5.9 increased risk for death, and risks are greater for males than for females.	—	—

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Most studies found underreporting by 11–41%	The food record is likely to significantly underreport EI when compared to TEE measured via the DLW method.	29/36 positive quality; 7/36 neutral quality	—	Partially well done/ reported
EI underreported by 8–30% in almost all studies	EI tends to be underreported on 24-hour recalls.	16/24 positive; 8/24 neutral	—	Partially well done/ reported
Significant underreporting found in all studies using an FFQ	FFQs tend to underestimate energy intake, particularly at the individual level.	14/21 positive; 7/21 neutral	—	Partially well done/ reported
Underreporting in 4 of 5 studies, ranging from 1 to 47%	Diet histories tend to underreport EI.	4/5 positive; 1/5 neutral	—	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Burrows et al., 2020	5	106 male and female children and adolescents	FFQ/TEE from DLW	EI-TEE
Burrows et al., 2020	4	66 male and female children and adolescents	WFR/TEE from DLW	EI-TEE
Burrows et al., 2020	3	108 male and female children and adolescents	Remote food photography/ TEE from DLW	EI-TEE
Burrows et al., 2020	2	52 male and female children and adolescents	24-hour recall / TEE from DLW	EI-TEE
Burrows et al., 2020	1	29 male and female children and adolescents	Precoded food record/TEE from DLW	EI-TEE
Capling et al., 2017	11	109 adolescent and adult male and female athletes; includes pregnant women; not all from high-income countries	Food record/ DLW	EI-TEE

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Significant underreporting in 3 of 5 studies (–7% to –23% of estimated EI); other 2 studies were small (*n* = 9 or 12), one had a higher mean EI on FFQ vs. TEE from DLW, the other was lower	FFQ has limitations for assessing EI, especially at the individual level.	4/5 positive quality; 1 neutral quality	—	Partially well done/ reported
Significant underreporting in 1 of 4 studies (–10% of estimated EI)	Only 1 study concluded the tool may be useful in individual children; it may not be accurate at the individual level.	4/4 positive	—	Partially well done/ reported
Differences ranged from –16% to +7%. One study found no significant difference between reported and measured values; one found remote food photography method was not valid at the individual or group level.	There is limited ability to assess EI at the individual level.	—	—	Partially well done/ reported
One study found a difference of –23 (± 442 kcal); the second found a difference of –0.9%	The 24-hour recall was valid on the group level, but not at the individual level.	1/2 positive; 1/2 neutral	—	Partially well done/ reported
Overreporting by +24% ($p < .0001$); mean difference of 726 kJ/day	Method overestimated EI.	1/1 positive	—	Partially well done/ reported
Mean difference EI-TEE: –19%; –2,793 ± 1,134 kJ/day absolute difference; Effect size –1.01 (95% CI, –1.3, –0.7)	The food record is likely to significantly underreport estimated EI when compared with TEE estimated via DLW in athletes.	fair to moderate for most studies	—	Not well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Gemming et al., 2015	2	82 male and female adults; not all from high-income countries	Image-based food record / TEE from DLW	EI-TEE
Gemming et al., 2015	1	14 male and female adults; not all from high-income countries	Image-assisted 24-hour recall / TEE from DLW	EI-TEE
Ho et al., 2020	6	205 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/DLW	Total energy intake

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
Remote food photography underestimated by –6% to –26% in overweight and obese adults	Image-based food records are likely to underestimate EI.	—	—	Not well done/ reported
Image-assisted 24-hour recall overestimated by +7.6%	Image-assisted methods may overestimate EI.	—	—	Not well done/ reported
Four studies reported a lower mean EI as estimated by the IBDA method; two studies reported agreement and no bias between the IBDA and DLW. The weighted mean difference for IBDA and DLW methods was –448.04 kcal (–755.52, –140.56), but heterogeneity between studies was very high (I^2 = 95%), indicating substantial variability between studies.	A large weighted mean difference in energy intake showed significant energy underreporting with the IBDA methods when compared with DLW.	The overall quality of the 6 studies ranged from good to very good. Two studies were rated as very good quality with 9–10 points, and 4 studies were rated as good quality, with 7–8 points.	Heterogeneity between studies was very high (I^2 = 95%), indicating substantial variability between studies.	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Ho et al., 2020	4	142 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/24-hour dietary recall	Total energy intake
Ho et al., 2020	6	266 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/ weighted food record	Total energy intake

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
One study showed a significant positive correlation for EI between the IBDA and 24-hour methods, another study showed that the IBDA method underreported EI when compared with the 24-hour method, and the other two studies provided mean estimates but not statistical analyses. Weighted mean difference in EI for IBDAs and 24-hour recalls was –91.53 kcal (–151.45, 46.13); heterogeneity was high ($I^2 = 76\%$), indicating some variability between studies.	No statistically significant differences were found in the weighted mean differences of energy intake between the IBDAs and the 24-hour recalls.	The overall quality of the 4 studies ranged from good to very good. One study was rated as very good quality with 9–10 points, and 3 studies were rated as good quality with 7–8 points.	Heterogeneity was high ($I^2 = 76\%$), indicating some variability between studies.	Partially well done/ reported
Three studies reported good agreement in estimated EI, two studies reported an underestimation of EI using the IBDA methods, and one study reported an overestimation of EI using the IBDA method. Weighted mean difference in EI for IBDA and WFR was –52.66 kcal (–151.45, 46.13); Heterogeneity was high ($I^2 = 66\%$), indicating some variability between studies.	No statistically significant differences were found in the weighted mean differences of energy intake between the IBDAs and the WFRs.	The overall quality of the 6 studies ranged from good to very good. Two studies were rated as very good quality, with 9–10 points, and 4 studies were rated as good quality, with 7–8 points.	Heterogeneity was high ($I^2 = 66\%$), indicating some variability between studies.	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Ho et al., 2020	3	103 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/24-hour dietary recall	Macro-nutrients

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Heterogeneity of Studies	Overall AMSTAR2 Rating
One study showed a significant positive correlation for all three macronutrients, one study observed a significant difference in carbohydrate but not protein or fat intake, and the other study provided mean estimates but not statistical analyses. WMD in carbohydrate intake was –15.52 g (95% CI: –41.34, 10.30); heterogeneity was $I^2 = 66\%$ ($p = .05$). WMD in protein intake was 2.06 g (–3.16, 7.28); heterogeneity was $I^2 = 0\%$ ($p = .95$). WMD in fat intake was –2.90 g (–8.34, 2.55); heterogeneity was $I^2 = 0\%$ ($p = .44$).	No statistically significant differences in the weighted mean difference of carbohydrate, protein, or fat intake were observed between the IBDA and 24-hour recall methods.	The overall quality of the 3 studies ranged from good to very good. One study was rated as very good quality, with 9–10 points, and 2 studies were rated as good quality, with 7–8 points.	Heterogeneity was high ($I^2 = 66\%$) for carbohydrate intake, indicating some variability between studies, but was not present for protein ($I^2 = 0\%$; $p = .95$) or fat intake ($I^2 = 0\%$; $p = .44$).	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Ho et al., 2020	6	256 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/WFR	Macro-nutrients

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Three studies reported good agreement in estimated macronutrients between the two methods, two studies reported no difference in macronutrient intake between the IBDA and WFR, and one study reported that the IBDA overestimated carbohydrate, protein, and fat intake. WMD in carbohydrate intake for IBDAs and WFRs was –6.71 g (–20.2, 6.79); heterogeneity was $I^2 = 63\%$ ($p = 0.02$). WMD in protein intake for IBDAs and WFRs was –0.85 g (–6.10, 4.40); heterogeneity was high ($I^2 = 77\%$). WMD in fat intake for IBDAs and WFRs was –0.30 g (–2.65, 2.05); heterogeneity was low ($I^2 = 21\%$; $p = .28$).	No statistically significant differences in the WMD of carbohydrate, protein, or fat intake were observed between the IBDA and WFR methods.	The overall quality of the 6 studies ranged from good to very good. Two studies were rated as very good quality, with 9–10 points, and 4 studies were rated as good quality, with 7–8 points.	Heterogeneity was moderate to high for carbohydrate ($I^2 = 63\%$; $p = .02$) and protein intake ($I^2 = 77\%$; $p < .01$), but low for fat intake ($I^2 = 21\%$; $p = .28$).	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Ho et al., 2020	2	53 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/24-hour dietary recall	Micro-nutrients
Ho et al., 2020	3	152 children and adults, males and females; includes pregnant women	Image-based dietary assessment method/WFR	Micro-nutrients

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
One study showed a significant positive correlation with iron and vitamin C, and the other study provided mean estimates but not statistical analyses. WMD in iron intake for IBDAs and 24-hour recall was 0.39 mg (95% CI: –0.81, 1.59); heterogeneity was $I^2 = 0\%$ ($p = .38$). WMD in vitamin C intake was 9.14 mg (–13.16, 31.45); heterogeneity was $I^2 = 0\%$ ($p = .56$).	No statistically significant differences were found in the WMDs of iron or vitamin C intake.	One study was rated as very good quality, with 9–10 points, and 1 study was rated as good quality, with 7–8 points.	Heterogeneity was not present for iron ($I^2 = 0\%$; $p = .38$) or vitamin C intake ($I^2 = 0\%$; $p = .56$).	Partially well done/ reported
One study showed a significant positive correlation with iron and vitamin C for the IBDA and the WFR, another study showed a significant positive correlation with vitamin C, and the other study showed no difference in micronutrient intake (both iron and vitamin C) between the two methods. The WMD in iron intake was –0.19 g (95% CI: –0.78, 0.40); heterogeneity was $I^2 = 3\%$ ($p = .36$). The WMD in vitamin C intake was –10.97 g (–39.95, 18.01); heterogeneity was $I^2 = 89\%$ ($p < .01$).	No statistically significant differences were found in the WMDs of iron or vitamin C intake.	The overall quality of the 3 studies ranged from good to very good. One study was rated as very good quality, with 9–10 points, and 2 studies were rated as good quality, with 7–8 points.	Heterogeneity was minimal for iron intake ($I^2 = 3\%$; $p = 0.36$) but quite substantial for vitamin C intake ($I^2 = 89\%$; $p < .01$).	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Tugault-Lafleur et al., 2017	15	2,576 school-aged children	School meal recalls/ observational method (i.e., in-person meal observations, digital photography, WMD	Relative accuracy
Tugault-Lafleur et al., 2017	1	24 school-aged children	Estimated food records/ observational method (i.e., in-person meal observation	Relative accuracy
Tugault-Lafleur et al., 2017	1	46 school-aged children	FFQs/4-day estimated food record	Relative accuracy

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Poor accuracy for individual foods reported (omission and intrusion rates > 15%, n = 8 of 12 studies). Acceptable accuracy when reporting amounts consumed (n = 4 of 5 studies). Acceptable energy report rates (n = 2 of 3 studies).	The relative accuracy of school meal recalls is poor for individual foods reported but is acceptable for reporting the estimated energy intake of a group.	—	—	Not well done/ reported
Pearson correlations ranged from r = 0.16 to r = 0.85 for different meal components (mean r = 0.66) under a daily monitoring approach. For the weekly monitoring approach, Pearson correlation coefficients ranged from r = –0.21 to r = 0.69 (mean, r = 0.25)	The estimated food record had acceptable accuracy with daily monitoring but poor accuracy with weekly monitoring.	—	—	Not well done/ reported
The Pearson correlation coefficients were r = 0.71, 0.70, and 0.69 for beverages, snacks, and total fruits and vegetables, respectively. Mean, r = 0.69 for all food and beverage items; $p < .05$.	Acceptable accuracy for measuring select beverages and snack foods; the majority of the 19 questions assessing in-school dietary intakes were significantly associated with amounts obtained from the estimated food record.	—	—	Not well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Tugault-Lafleur et al., 2017	2	1,149 school-aged children	DP methods/ WFRs	Relative accuracy

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
In the first study, correlation coefficients indicated strong positive correlations, ranging from 0.89 to 0.97, and no statistically significant differences were found in mean amounts for differences in lunch meal components estimated by using the DP and the WFRs. Bland-Altman analyses suggested a tendency to slightly underestimate fruit (mean bias, –4.27 g) and vegetables (mean bias, 6.19g). In the second study, all 11 school meal items had a correlation coefficient > 0.70, with correlations ranging from r = 0.76 to r = 0.98, except for leafy greens (r = 0.59) and lasagna (r = 0.62). The group's mean for meal items was within 1 g of the reference method (i.e., WFRs), and no evidence of bias in Bland-Altman analyses.	The findings from the two studies suggest that the DP method is a valid method for estimating the dietary intakes, in terms of the types and amounts of foods consumed, of both home-packed and school lunches.	—	—	Not well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Tugault-Lafleur et al., 2017	2	282 school-aged children	The SFC/ observational method (i.e., in-person meal observations, DP, WFRs)	Relative accuracy and reliability

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
In the first study, the mean difference in estimated EI between the WFTR and the SFC was 15 kJ (95% CI: 107 to 138; $p > .05$), providing acceptable accuracy to measure energy intake for the group. The second study showed that the ICCs for intrarater reliability ranged from 0.57 to 1.0 for different meal components, suggesting good intrarater reliability. The ICCs for interrater reliability tended to be higher (> 0.7). Thus, interrater reliability was deemed acceptable for most meal components (all except noodles and leftovers).	The relative accuracy of the SFC for measuring energy intake is acceptable. The SFC has acceptable interrater reliability and good intrarater reliability.	—	—	Not well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Wehling and Lusher, 2019	13	4,172 obese adults (BMI ≥ 30)	Diet records/ reference method for assessing energy intake	Accuracy of self-report EI via diet records

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Among the obese population, nine studies reported the percent of the population who underreported EI, with estimates ranging from 19% to 82% underreporting depending on the study setting (clinical vs. free living) and the demographic characteristics of the study population; another study reported 79.6% mean reporting accuracy of EI; one study reported overall misreport of energy intake, which was 46%.	The present findings show a consistent and clear link between underreporting of energy intake and an obese BMI in a considerable number of papers included.	The quality of the included papers generally ranged between 50% and 100%. The most common result was 63% (11 studies), which was primarily due to non-random sampling and using specific groups. Eight studies had small samples that were unlikely to result in adequate power for the statistics applied. The majority of studies were at least average (7) or large (19), suggesting a higher generalizability.	—	Partially well done/reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Wehling and Lusher, 2019	12	6,363 obese adults (BMI ≥ 30)	24-hour dietary recall/reference method for assessing energy intake	Accuracy of self-report EI via 24-hour recall

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
Among the obese population, one study found that reporting of actual intake ranged from 90% to 98% depending on whether the participant had binge eating disorder. Another study found that participants who underreport EI are more likely to be overweight/obese (61.7%; p = .032), and a different study showed that underreporting is associated with older age, higher BMI ($p < .01$), and female sex ($p < .001$). Similarly, Lichtman et al. found that obese participants under diet resistance underreported intake by 20% ($p < .05$). Whereas, two other studies found that underreporting among the obese population was not significantly different than among those with a normal weight (30.3% vs. 31.1%), and that BMI has no effect on the accuracy of self-reported EI (p = .19).	The present findings show a consistent and clear link between underreporting of energy intake and an obese BMI in a considerable number of papers included.	The quality of the included papers generally ranged between 50% and 100%. The most common result was 63% (11 studies), which was primarily due to non-random sampling and using specific groups. Eight studies had small samples that were unlikely to result in adequate power for the statistics applied. The majority of studies were at least average (7) or large (19), suggesting a higher generalizability.	—	Partially well done/reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Wehling and Lusher, 2019	9	22,104 obese adults (BMI ≥ 30)	FFQ/reference method for assessing energy intake	Accuracy of self-reported EI via FFQs

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
The average proportion of underreporting in five studies ranged from 16.8% to 77.5%, depending on the study setting (clinical vs. free living) and the demographic characteristics of the study population. One study reporting overall misreport indicated that 46% of obese adults misreport EI. One study reported a small influence of BMI on underreporting of EI among postmenopausal women (8.1%), whereas another study reported considerable underreporting of energy among obese twins, when compared with their normal-weight twin counterparts (3.2 ± 1.1 MJ/day; $p = .036$). A different study among obese females found that underreporting was significantly higher among obese individuals when compared with those in lower BMI categories ($p < .05$), but underreporting varied across dietary instruments, and the FFQ had the lowest accuracy.	The present findings show a consistent and clear link between underreporting of energy intake and an obese BMI in a considerable number of papers included.	The quality of the included papers generally ranged between 50% and 100%. The most common result was 63% (11 studies), which was primarily due to non-random sampling and using specific groups. Eight studies had small samples that were unlikely to result in adequate power for the statistics applied. The majority of studies were at least average (7) or large (19), suggesting a higher generaliz-ability.	—	Partially well done/ reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Wehling and Lusher, 2019	4	1,217 obese adults (BMI ≥ 30)	Food diaries/ reference method for assessing energy intake	Accuracy of self-reported EI via food diaries

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
One study found that low energy reporters have significantly higher BMI when compared with non–low energy reporters, regardless of sex (27.5 vs. 25.7 in males, 27.99 vs. 25.4 in females) and that obesity is the highest predictor ($p < .01$) of underreporting of energy. Another study showed that 52% of overweight and obese unsuccessful dieters underreported their EI, whereas a different study found that underreporting is considerable for obese twins, when compared with their normal-weight twin counterparts (3.2 ± 1.1 MJ/day; $p = .036$). Lastly, another study found that obese females underreport their energy by 8.8% and that obese females consumed significantly more energy (especially from the energy-dense category) when compared with their non-obese female counterparts.	The present findings show a consistent and clear link between underreporting of EI and an obese BMI in a considerable number of papers included.	The quality of the included papers generally ranged between 50% and 100%. The most common result was 63% (11 studies), which was primarily due to non-random sampling and using specific groups. Eight studies had small samples that were unlikely to result in adequate power for the statistics applied. The majority of studies were at least average (7) or large (19), suggesting a higher generalizability.	—	Partially well done/reported

continued

TABLE J-14 Continued

Author, Year	Number of Studies	Sample Characteristics	Intervention / Comparator	Primary Outcome
Wehling and Lusher, 2019	3	23,482 obese adults (BMI ≥ 30)	DHQ/reference method for assessing energy intake	Accuracy of self-reported EI via the DHQ

NOTE: BMI = body mass index; CI = confidence interval; DHQ = diet history questionnaire; DLW = doubly labeled water; DP = digital photography; EI = energy intake; FFQ = food frequency questionnaire; FR = food record; IBDA = image-based dietary assessment; ICC = intraclass correlation coefficient; MJ = megajoule; SFC = School Food Checklist; TEE = total energy expenditure; WFR = weighted food record; WMD = weighted mean difference.

Quantitative Finding(s)	Qualitative Finding(s)	Risk of Bias	Hetero-geneity of Studies	Overall AMSTAR2 Rating
One study found that 17.5% of obese females and 5.5% of obese males underreport EI, and that no significant differences in accuracy of reporting exists when compared with nonobese females and males. Similarly, another study showed that underreporting is more common among those with a BMI > 30, and energy underreporting in this population is approximately 91% on a DHQ. Lastly, another study found that approximately 16% of obese adults were overreporters and 66% were underreporters. The mean level of underreporting was approximately 18.0 ± 29.1%	The present findings show a consistent and clear link between underreporting of EI and an obese BMI in a considerable number of papers included.	The quality of the included papers generally ranged between 50% and 100%. The most common result was 63% (11 studies), which was primarily due to non-random sampling and using specific groups. Eight studies had small samples that were unlikely to result in adequate power for the statistics applied. The majority of studies were at least average (7) or large (19), suggesting a higher generalizability.	—	Partially well done/ reported

REFERENCES

Abeysekera, M. V., J. A. Morris, G. K. Davis, and A. J. O'Sullivan. 2016. Alterations in energy homeostasis to favour adipose tissue gain: A longitudinal study in healthy pregnant women. *Australia and New Zealand Journal of Obstetrics and Gynaecology* 56(1):42-48.

Adamo, K. B., S. A. Prince, A. C. Tricco, S. Connor-Gorber, and M. Tremblay. 2009. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: A systematic review. *International Journal of Pediatric Obesity* 4(1):2-27.

Adzika Nsatimba, P. A., K. Pathak, and M. J. Soares. 2016. Ethnic differences in resting metabolic rate, respiratory quotient and body temperature: A comparison of Africans and European Australians. *European Journal of Nutrition* 55(5):1831-1838.

Albu, J., M. Shur, M. Curi, L. Murphy, S. B. Heymsfield, and F. X. Pi-Sunyer. 1997. Resting metabolic rate in obese, premenopausal black women. *American Journal of Clinical Nutrition* 66(3):531-538.

Alharbi, T. A., S. Paudel, D. Gasevic, J. Ryan, R. Freak-Poli, and A. J. Owen. 2021. The association of weight change and all-cause mortality in older adults: A systematic review and meta-analysis. *Age & Ageing* 50(3):697-704.

Ashtary-Larky, D., R. Bagheri, A. Abbasnezhad, G. M. Tinsley, M. Alipour, and A. Wong. 2020. Effects of gradual weight loss v. rapid weight loss on body composition and RMR: A systematic review and meta-analysis. *British Journal of Nutrition* 124(11):1121-1132.

Azizpour, Y., A. Delpisheh, Z. Montazeri, K. Sayehmiri, and B. Darabi. 2018. Effect of childhood BMI on asthma: A systematic review and meta-analysis of case-control studies. *BMC Pediatrics* 18(1):143.

Bailly, M., A. Boscaro, B. Pereira, L. Feasson, Y. Boirie, N. Germain, B. Galusca, D. Courteix, D. Thivel, and J. Verney. 2021. Is constitutional thinness really different from anorexia nervosa? A systematic review and meta-analysis. *Reviews in Endocrine and Metabolic Disorders* 22(4):913-971.

Bandini, L. G., A. Must, J. L. Spadano, and W. H. Dietz. 2002. Relation of body composition, parental overweight, pubertal stage, and race-ethnicity to energy expenditure among premenarcheal girls. *American Journal of Clinical Nutrition* 76(5):1040-1047.

Berggren, E. K., L. Presley, S. B. Amini, S. Hauguel-de Mouzon, and P. M. Catalano. 2015. Are the metabolic changes of pregnancy reversible in the first year postpartum? *Diabetologia* 58(7):1561-1568.

Blanc, S., D. A. Schoeller, D. Bauer, M. E. Danielson, F. Tylavsky, E. M. Simonsick, T. B. Harris, S. B. Kritchevsky, and J. E. Everhart. 2004. Energy requirements in the eighth decade of life. *American Journal of Clinical Nutrition* 79(2):303-310.

Bosy-Westphal, A., B. Schautz, M. Lagerpusch, M. Pourhassan, W. Braun, K. Goele, M. Heller, C. C. Glüer, and M. J. Müller. 2013. Effect of weight loss and regain on adipose tissue distribution, composition of lean mass and resting energy expenditure in young overweight and obese adults. *International Journal of Obesity (Lond)* 37(10):1371-1377.

Broadney, M. M., F. Shareef, S. E. Marwitz, S. M. Brady, S. Z. Yanovski, J. P. DeLany, and J. A. Yanovski. 2018. Evaluating the contribution of differences in lean mass compartments for resting energy expenditure in African American and Caucasian American children. *Pediatric Obesity* 13(7):413-420.

Burrows, T. L., Y. Y. Ho, M. E. Rollo, and C. E. Collins. 2019. Validity of dietary assessment methods when compared to the method of doubly labeled water: A systematic review in adults. *Frontiers in Endocrinology* 10.

Burrows, T., S. Goldman, and M. Rollo. 2020. A systematic review of the validity of dietary assessment methods in children when compared with the method of doubly labelled water. *European Journal of Clinical Nutrition* 74(5):669-681.

Byrne, N. M., R. L. Weinsier, G. R. Hunter, R. Desmond, M. A. Patterson, B. E. Darnell, and P. A. Zuckerman. 2003. Influence of distribution of lean body mass on resting metabolic rate after weight loss and weight regain: Comparison of responses in white and black women. *American Journal of Clinical Nutrition*77(6):1368-1373.

Byun, D., S. Hong, S. Ryu, Y. Nam, H. Jang, Y. Cho, N. Keum, and H. Oh. 2022. Early-life body mass index and risks of breast, endometrial, and ovarian cancers: A dose-response meta-analysis of prospective studies. *British Journal of Cancer* 126(4):664-672.

Campbell, P. T., C. C. Newton, N. D. Freedman, J. Koshiol, M. C. Alavanja, L. E. Beane Freeman, J. E. Buring, A. T. Chan, D. Q. Chong, M. Datta, M. M. Gaudet, J. M. Gaziano, E. L. Giovannucci, B. I. Graubard, A. R. Hollenbeck, L. King, I. M. Lee, M. S. Linet, J. R. Palmer, J. L. Petrick, J. N. Poynter, M. P. Purdue, K. Robien, L. Rosenberg, V. V. Sahasrabuddhe, C. Schairer, H. D. Sesso, A. J. Sigurdson, V. L. Stevens, J. Wactawski-Wende, A. Zeleniuch-Jacquotte, A. G. Renehan, and K. A. McGlynn. 2016. Body mass index, waist circumference, diabetes, and risk of liver cancer for U.S. Adults. *Cancer Research* 76(20):6076-6083.

Capling, L., K. L. Beck, J. A. Gifford, G. Slater, V. M. Flood, and H. O'Connor. 2017. Validity of dietary assessment in athletes: A systematic review. *Nutrients* 9(12).

Capristo, E., A. Maione, G. Lucisano, M. F. Russo, G. Mingrone, and A. Nicolucci. 2021. Effects of weight loss medications on mortality and cardiovascular events: A systematic review of randomized controlled trials in adults with overweight and obesity. *Nutrition, Metabolism, and Cardiovascular Diseases* 31(9):2587-2595.

Catalano, P. M., N. M. Roman-Drago, S. B. Amini, and E. A. Sims. 1998. Longitudinal changes in body composition and energy balance in lean women with normal and abnormal glucose tolerance during pregnancy. *American Journal of Obstetrics and Gynecology* 179(1):156-165.

Chan, D. S. M., L. Abar, M. Cariolou, N. Nanu, D. C. Greenwood, E. V. Bandera, A. McTiernan, and T. Norat. 2019. World cancer research fund international: Continuous update project-systematic literature review and meta-analysis of observational cohort studies on physical activity, sedentary behavior, adiposity, and weight change and breast cancer risk. *Cancer Causes and Control* 30(11):1183-1200.

Cheng, H. L., M. Amatoury, and K. Steinbeck. 2016. Energy expenditure and intake during puberty in healthy nonobese adolescents: A systematic review. *American Journal of Clinical Nutrition* 104(4):1061-1074.

Christin, L., M. O'Connell, C. Bogardus, E. Danforth, Jr., and E. Ravussin. 1993. Norepinephrine turnover and energy expenditure in Pima Indian and White men. *Metabolism* 42(6):723-729.

Church, T. S., M. J. LaMonte, C. E. Barlow, and S. N. Blair. 2005. Cardiorespiratory fitness and body mass index as predictors of cardiovascular disease mortality among men with diabetes. *Archives of Internal Medicine* 165(18):2114-2120.

Cisneros, L. C. V., A. G. M. Moreno, A. Lopez-Espinoza, and A. C. Espinoza-Gallardo. 2019. Effect of the fatty acid composition of meals on postprandial energy expenditure: A systematic review. *Revista da Associacao Medica Brasileira (1992)* 65(7):1022-1031.

Craigie, A. M., A. A. Lake, S. A. Kelly, A. J. Adamson, and J. C. Mathers. 2011. Tracking of obesity-related behaviours from childhood to adulthood: A systematic review. *Maturitas* 70(3):266-284.

Darbandi, M., Y. Pasdar, S. Moradi, H. J. J. Mohamed, B. Hamzeh, and Y. Salimi. 2020. Discriminatory capacity of anthropometric indices for cardiovascular disease in adults: A systematic review and meta-analysis. *Preventing Chronic Disease* 17:E131.

Deemer, S. E., G. A. King, S. Dorgo, C. A. Vella, J. W. Tomaka, and D. L. Thompson. 2010. Relationship of leptin, resting metabolic rate, and body composition in premenopausal Hispanic and non-Hispanic white women. *Endocrinology Research* 35(3):95-105.

DeLany, J. P., G. A. Bray, D. W. Harsha, and J. Volaufova. 2002. Energy expenditure in preadolescent African American and white boys and girls: The Baton Rouge Children's Study. *American Journal of Clinical Nutrition* 75(4):705-713.

DeLany, J. P., G. A. Bray, D. W. Harsha, and J. Volaufova. 2006. Energy expenditure and substrate oxidation predict changes in body fat in children. *American Journal of Clinical Nutrition* 84(4):862-870.

DeLany, J. P., J. M. Jakicic, J. B. Lowery, K. C. Hames, D. E. Kelley, and B. H. Goodpaster. 2014. African American women exhibit similar adherence to intervention but lose less weight due to lower energy requirements. *International Journal of Obesity (London)* 38(9):1147-1152.

Désilets, M. C., D. Garrel, C. Couillard, A. Tremblay, J. P. Després, C. Bouchard, and H. Delisle. 2006. Ethnic differences in body composition and other markers of cardiovascular disease risk: Study in matched Haitian and white subjects from Quebec. *Obesity (Silver Spring)* 14(6):1019-1027.

Dhurandhar, E. J., K. A. Kaiser, J. A. Dawson, A. S. Alcorn, K. D. Keating, and D. B. Allison. 2015. Predicting adult weight change in the real world: A systematic review and meta-analysis accounting for compensatory changes in energy intake or expenditure. *International Journal of Obesity* 39(8):1181-1187.

Dombrowski, S. U., K. Knittle, A. Avenell, V. Araújo-Soares, and F. F. Sniehotta. 2014. Long-term maintenance of weight loss with non-surgical interventions in obese adults: Systematic review and meta-analyses of randomised controlled trials. *BMJ* 348:g2646.

Dowd, K. P., R. Szeklicki, M. A. Minetto, M. H. Murphy, A. Polito, E. Ghigo, H. van der Ploeg, U. Ekelund, J. Maciaszek, R. Stemplewski, M. Tomczak, and A. E. Donnelly. 2018. A systematic literature review of reviews on techniques for physical activity measurement in adults: A dedipac study. *International Journal of Behavioral Nutrition and Physical Activity* 15(1).

Dugani, S. B., Y. M. Hydoub, A. P. Ayala, R. Reka, T. Nayfeh, J. F. Ding, S. N. McCafferty, M. Alzuabi, M. Farwati, M. H. Murad, A. A. Alsheikh-Ali, and S. Mora. 2021. Risk factors for premature myocardial infarction: A systematic review and meta-analysis of 77 studies. *Mayo Clinic Proceedings: Innovations, Quality and Outcomes* 5(4):783-794.

Dugas, L. R., K. Ebersole, D. Schoeller, J. A. Yanovski, S. Barquera, J. Rivera, R. Durazo-Arzivu, and A. Luke. 2008. Very low levels of energy expenditure among pre-adolescent Mexican-American girls. *International Journal of Pediatric Obesity* 3(2):123-126.

Dugas, L. R., R. Cohen, M. T. Carstens, P. F. Schoffelen, A. Luke, R. A. Durazo-Arvizu, J. H. Goedecke, N. S. Levitt, and E. V. Lambert. 2009. Total daily energy expenditure in black and white, lean and obese South African women. *European Journal of Clinical Nutrition* 63(5):667-673.

El Ghoch, M., S. Calugi, and R. Dalle Grave. 2018. Weight cycling in adults with severe obesity: A longitudinal study. *Nutrition and Dietetics* 75(3):256-262.

Fang, X., J. Wei, X. He, J. Lian, D. Han, P. An, T. Zhou, S. Liu, F. Wang, and J. Min. 2018. Quantitative association between body mass index and the risk of cancer: A global meta-analysis of prospective cohort studies. *International Journal of Cancer* 143(7):1595-1603.

Fontvieille, A. M., J. Dwyer, and E. Ravussin. 1992. Resting metabolic rate and body composition of Pima Indian and Caucasian children. *International Journal of Obesity and Related Metabolic Disorders* 16(8):535-542.

Fontvieille, A. M., R. Rising, M. Spraul, D. E. Larson, and E. Ravussin. 1994. Relationship between sleep stages and metabolic rate in humans. *American Journal of Physiology* 267(5 Pt 1):E732-E737.

Forman, J. N., W. C. Miller, L. M. Szymanski, and B. Fernhall. 1998. Differences in resting metabolic rates of inactive obese African-American and Caucasian women. *International Journal of Obesity and Related Metabolic Disorders* 22(3):215-221.

Foster, G. D., T. A. Wadden, R. M. Swain, D. A. Anderson, and R. A. Vogt. 1999. Changes in resting energy expenditure after weight loss in obese African American and white women. *American Journal of Clinical Nutrition* 69(1):13-17.

Fothergill, E., J. Guo, L. Howard, J. C. Kerns, N. D. Knuth, R. Brychta, K. Y. Chen, M. C. Skarulis, M. Walter, P. J. Walter, and K. D. Hall. 2016. Persistent metabolic adaptation 6 years after "The Biggest Loser" competition. *Obesity (Silver Spring)* 24(8):1612-1619.

Foulds, H. J. A., D. E. R. Warburton, and S. S. D. Bredin. 2013. A systematic review of physical activity levels in Native American populations in Canada and the United States in the last 50 years. *Obesity Reviews* 14(7):593-603.

Gallagher, D., M. Visser, R. E. De Meersman, D. Sepúlveda, R. N. Baumgartner, R. N. Pierson, T. Harris, and S. B. Heymsfield. 1997. Appendicular skeletal muscle mass: Effects of age, gender, and ethnicity. *Journal of Applied Physiology (1985)* 83(1):229-239.

Gallagher, D., J. Albu, Q. He, S. Heshka, L. Boxt, N. Krasnow, and M. Elia. 2006. Small organs with a high metabolic rate explain lower resting energy expenditure in African American than in white adults. *American Journal of Clinical Nutrition* 83(5):1062-1067.

Gao, J., X. Lin, Y. He, Y. Fu, Y. Wu, J. Liao, Y. Wu, and X. Lian. 2019. The comparison of different obesity indexes and the risk of lung cancer: A meta-analysis of prospective cohort studies. *Nutrition & Cancer* 71(6):908-921.

Gemming, L., J. Utter, and C. Ni Mhurchu. 2015. Image-assisted dietary assessment: A systematic review of the evidence. *Journal of the Academy of Nutrition & Dietetics* 115(1):64-77.

Glass, J. N., W. C. Miller, L. M. Szymanski, B. Fernhall, and J. L. Durstine. 2002. Physiological responses to weight-loss intervention in inactive obese African-American and Caucasian women. *Journal of Sports Medicine and Physical Fitness* 42(1):56-64.

Goran, M. I., M. Kaskoun, R. Johnson, C. Martinez, B. Kelly, and V. Hood. 1995. Energy expenditure and body fat distribution in Mohawk children. *Pediatrics* 95(1):89-95.

Goran, M. I., T. R. Nagy, B. A. Gower, M. Mazariegos, N. Solomons, V. Hood, and R. Johnson. 1998. Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: Implications for energy requirements. *American Journal of Clinical Nutrition* 68(3):675-682.

Gu, D., M. Tang, Y. Wang, H. Cui, M. Zhang, Y. Bai, Z. Zeng, Y. Tan, X. Wang, and B. Zhang. 2022. The causal relationships between extrinsic exposures and risk of prostate cancer: A phenome-wide mendelian randomization study. *Frontiers in Oncology* 12.

Hanks, L. J., O. M. Gutiérrez, A. P. Ashraf, and K. Casazza. 2015. Bone mineral content as a driver of energy expenditure in prepubertal and early pubertal boys. *Journal of Pediatrics* 166(6):1397-1403.

Hao, Y., M. Jiang, Y. Miao, X. Li, C. Hou, X. Zhang, H. Chen, X. Zhong, and J. Li. 2021. Effect of long-term weight gain on the risk of breast cancer across women's whole adulthood as well as hormone-changed menopause stages: A systematic review and dose-response meta-analysis. *Obesity Research and Clinical Practice* 15(5):439-448.

Helmerhorst, H. J., S. Brage, J. Warren, H. Besson, and U. Ekelund. 2012. A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. *International Journal of Behavioral Nutrition & Physical Activity* 9:103.

Heymsfield, S. B., J. B. Harp, M. L. Reitman, J. W. Beetsch, D. A. Schoeller, N. Erondu, and A. Pietrobelli. 2007. Why do obese patients not lose more weight when treated with low-calorie diets? A mechanistic perspective. *American Journal of Clinical Nutrition* 85(2):346-354.

Hidayat, K., C. M. Yang, and B. M. Shi. 2018a. Body fatness at a young age, body fatness gain and risk of breast cancer: Systematic review and meta-analysis of cohort studies. *Obesity Reviews* 19(2):254-268.

Hidayat, K., H. J. Li, and B. M. Shi. 2018b. Anthropometric factors and non-Hodgkin's lymphoma risk: Systematic review and meta-analysis of prospective studies. *Critical Reviews in Oncology-Hematology* 129:113-123.

Hidayat, K., S. Y. Zou, and B. M. Shi. 2019. The influence of maternal body mass index, maternal diabetes mellitus, and maternal smoking during pregnancy on the risk of childhood-onset type 1 diabetes mellitus in the offspring: Systematic review and meta-analysis of observational studies. *Obesity Reviews* 20(8):1106-1120.

Ho, D. K. N., S. H. Tseng, M. C. Wu, C. K. Shih, A. P. Atika, Y. C. Chen, and J. S. Chang. 2020. Validity of image-based dietary assessment methods: A systematic review and meta-analysis. *Clinical Nutrition* 39(10):2945-2959.

Hunter, G. R., R. L. Weinsier, B. E. Darnell, P. A. Zuckerman, and M. I. Goran. 2000. Racial differences in energy expenditure and aerobic fitness in premenopausal women. *American Journal of Clinical Nutrition* 71(2):500-506.

Ibe, A., and T. C. Smith. 2014. Diabetes in US women on the rise independent of increasing BMI and other risk factors: A trend investigation of serial cross-sections. *BMC Public Health* 14:954.

Jakicic, J. M., and R. R. Wing. 1998. Differences in resting energy expenditure in African-American vs Caucasian overweight females. *International Journal of Obesity and Related Metabolic Disorders* 22(3):236-242.

Jarvis, H., D. Craig, R. Barker, G. Spiers, D. Stow, Q. M. Anstee, and B. Hanratty. 2020. Metabolic risk factors and incident advanced liver disease in non-alcoholic fatty liver disease (NAFLD): A systematic review and meta-analysis of population-based observational studies. *PLoS Medicine / Public Library of Science* 17(4):e1003100.

Javed, F., Q. He, L. E. Davidson, J. C. Thornton, J. Albu, L. Boxt, N. Krasnow, M. Elia, P. Kang, S. Heshka, and D. Gallagher. 2010. Brain and high metabolic rate organ mass: Contributions to resting energy expenditure beyond fat-free mass. *American Journal of Clinical Nutrition* 91(4):907-912.

Jayedi, A., A. Rashidy-Pour, M. Khorshidi, and S. Shab-Bidar. 2018. Body mass index, abdominal adiposity, weight gain and risk of developing hypertension: A systematic review and dose-response meta-analysis of more than 2.3 million participants. *Obesity Reviews* 19(5):654-667.

Jayedi, A., A. Rashidy-Pour, S. Soltani, M. S. Zargar, A. Emadi, and S. Shab-Bidar. 2020. Adult weight gain and the risk of cardiovascular disease: A systematic review and dose-response meta-analysis of prospective cohort studies. *European Journal of Clinical Nutrition* 74(9):1263-1275.

Jayedi, A., S. Soltani, S. Z. Motlagh, A. Emadi, H. Shahinfar, H. Moosavi, and S. Shab-Bidar. 2022. Anthropometric and adiposity indicators and risk of type 2 diabetes: Systematic review and dose-response meta-analysis of cohort studies. *BMJ* 376:e067516.

Jeran, S., A. Steinbrecher, and T. Pischon. 2016. Prediction of activity-related energy expenditure using accelerometer-derived physical activity under free-living conditions: A systematic review. *International Journal of Obesity* 40(8):1187-1197.

Jiang, M., Y. Zou, Q. Xin, Y. Cai, Y. Wang, X. Qin, and D. Ma. 2019. Dose-response relationship between body mass index and risks of all-cause mortality and disability among the elderly: A systematic review and meta-analysis. *Clinical Nutrition* 38(4):1511-1523.

Jones, A., Jr., W. Shen, M. P. St-Onge, D. Gallagher, S. Heshka, Z. Wang, and S. B. Heymsfield. 2004. Body-composition differences between African American and white women: Relation to resting energy requirements. *American Journal of Clinical Nutrition* 79(5):780-786.

Karahalios, A., D. R. English, and J. A. Simpson. 2017. Change in body size and mortality: A systematic review and meta-analysis. *International Journal of Epidemiology* 46(2):526-546.

Katzmarzyk, P. T., J. Most, L. M. Redman, J. Rood, and E. Ravussin. 2018. Energy expenditure and substrate oxidation in white and African American young adults without obesity. *European Journal of Clinical Nutrition* 72(6):920-922.

Kee, A. L., E. Isenring, I. Hickman, and A. Vivanti. 2012. Resting energy expenditure of morbidly obese patients using indirect calorimetry: A systematic review. *Obesity Reviews* 13(9):753-765.

Khadra, D., L. Itani, H. Tannir, D. Kreidieh, D. El Masri, and M. El Ghoch. 2019. Association between sarcopenic obesity and higher risk of type 2 diabetes in adults: A systematic review and meta-analysis. *World Journal of Diabetes* 10(5):311-323.

Kim, K. S., W. L. Owen, D. Williams, and L. L. Adams-Campbell. 2000. A comparison between BMI and conicity index on predicting coronary heart disease: The Framingham Heart Study. *Annals of Epidemiology* 10(7):424-431.

Kim, M. S., W. J. Kim, A. V. Khera, J. Y. Kim, D. K. Yon, S. W. Lee, J. I. Shin, and H. H. Won. 2021. Association between adiposity and cardiovascular outcomes: An umbrella review and meta-analysis of observational and mendelian randomization studies. *European Heart Journal* 42(34):3388-3403.

Kitahara, C. M., A. J. Flint, A. Berrington de Gonzalez, L. Bernstein, M. Brotzman, R. J. MacInnis, S. C. Moore, K. Robien, P. S. Rosenberg, P. N. Singh, E. Weiderpass, H. O. Adami, H. Anton-Culver, R. Ballard-Barbash, J. E. Buring, D. M. Freedman, G. E. Fraser, L. E. Beane Freeman, S. M. Gapstur, J. M. Gaziano, G. G. Giles, N. Håkansson, J. A. Hoppin, F. B. Hu, K. Koenig, M. S. Linet, Y. Park, A. V. Patel, M. P. Purdue, C. Schairer, H. D. Sesso, K. Visvanathan, E. White, A. Wolk, A. Zeleniuch-Jacquotte, and P. Hartge. 2014. Association between class III obesity (BMI of 40-59 kg/m^2) and mortality: A pooled analysis of 20 prospective studies. *PLoS Med* 11(7):e1001673.

Kopp-Hoolihan, L. E., M. D. van Loan, W. W. Wong, and J. C. King. 1999. Longitudinal assessment of energy balance in well-nourished, pregnant women. *American Journal of Clinical Nutrition* 69(4):697-704.

Kushner, R. F., S. B. Racette, K. Neil, and D. A. Schoeller. 1995. Measurement of physical activity among black and white obese women. *Obesity Research* 3(Suppl 2):261s-265s.

Lam, Y. Y., L. M. Redman, S. R. Smith, G. A. Bray, F. L. Greenway, D. Johannsen, and E. Ravussin. 2014. Determinants of sedentary 24-h energy expenditure: Equations for energy prescription and adjustment in a respiratory chamber. *American Journal of Clinical Nutrition* 99(4):834-842.

Larsson, S. C., and S. Burgess. 2021. Causal role of high body mass index in multiple chronic diseases: A systematic review and meta-analysis of Mendelian randomization studies. *BMC Medicine* 19(1):320.

LeBlanc, E. S., C. D. Patnode, E. M. Webber, N. Redmond, M. Rushkin, and E. A. O'Connor. 2018. Behavioral and pharmacotherapy weight loss interventions to prevent obesity-related morbidity and mortality in adults updated evidence report and systematic review for the US Preventive Services Task Force. *JAMA* 320(11):1172-1191.

Li, H., D. Boakye, X. Chen, M. Hoffmeister, and H. Brenner. 2021. Association of body mass index with risk of early-onset colorectal cancer: Systematic review and meta-analysis. *American Journal of Gastroenterology* 116(11):2173-2183.

Li, Z. M., Z. X. Wu, B. Han, Y. Q. Mao, H. L. Chen, S. F. Han, J. L. Xia, and L. S. Wang. 2016. The association between BMI and gallbladder cancer risk: A meta-analysis. *Oncotarget* 7(28):43669-43679.

Lichtman, S. W., K. Pisarska, E. R. Berman, M. Pestone, H. Dowling, E. Offenbacher, H. Weisel, S. Heshka, D. E. Matthews, and S. B. Heymsfield. 1992. Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. *New England Journal of Medicine* 327(27):1893-1898.

Liu, X., D. Zhang, Y. Liu, X. Sun, Y. Hou, B. Wang, Y. Ren, Y. Zhao, C. Han, C. Cheng, F. Liu, Y. Shi, X. Chen, L. Liu, G. Chen, S. Hong, M. Zhang, and D. Hu. 2018a. A j-shaped relation of BMI and stroke: Systematic review and dose-response meta-analysis of 4.43 million participants. *Nutrition, Metabolism and Cardiovascular Diseases* 28(11):1092-1099.

Liu, X., Q. Sun, H. Hou, K. Zhu, Q. Wang, H. Liu, Q. Zhang, L. Ji, and D. Li. 2018b. The association between BMI and kidney cancer risk an updated dose-response meta-analysis in accordance with prisma guideline. *Medicine (United States)* 97(44).

Lovejoy, J. C., C. M. Champagne, S. R. Smith, L. de Jonge, and H. Xie. 2001. Ethnic differences in dietary intakes, physical activity, and energy expenditure in middle-aged, premenopausal women: The Healthy Transitions Study. *American Journal of Clinical Nutrition* 74(1):90-95.

Ludwig, D. S., S. L. Dickinson, B. Henschel, C. B. Ebbeling, and D. B. Allison. 2021. Do lower-carbohydrate diets increase total energy expenditure? An updated and reanalyzed meta-analysis of 29 controlled-feeding studies. *Journal of Nutrition* 151(3):482-490.

Ma, C., A. Avenell, M. Bolland, J. Hudson, F. Stewart, C. Robertson, P. Sharma, C. Fraser, and G. MacLennan. 2017. Effects of weight loss interventions for adults who are obese on mortality, cardiovascular disease, and cancer: Systematic review and meta-analysis. *BMJ* 359:j4849.

Manini, T. M., K. V. Patel, D. C. Bauer, E. Ziv, D. A. Schoeller, D. C. Mackey, R. Li, A. B. Newman, M. Nalls, J. M. Zmuda, and T. B. Harris. 2011. European ancestry and resting metabolic rate in older African Americans. *European Journal of Clinical Nutrition* 65(6):663-667.

Martin, K., P. Wallace, P. F. Rust, and W. T. Garvey. 2004. Estimation of resting energy expenditure considering effects of race and diabetes status. *Diabetes Care* 27(6):1405-1411.

McDuffie, J. R., D. C. Adler-Wailes, J. Elberg, E. N. Steinberg, E. M. Fallon, A. M. Tershakovec, S. A. Arslanian, J. P. Delany, G. A. Bray, and J. A. Yanovski. 2004. Prediction equations for resting energy expenditure in overweight and normal-weight black and white children. *American Journal of Clinical Nutrition* 80(2):365-373.

Meigs, J. B., P. W. Wilson, C. S. Fox, R. S. Vasan, D. M. Nathan, L. M. Sullivan, and R. B. D'Agostino. 2006. Body mass index, metabolic syndrome, and risk of type 2 diabetes or cardiovascular disease. *Journal of Clinical Endocrinology and Metabolism* 91(8):2906-2912.

Mika Horie, L., M. C. González, M. Raslan, R. Torrinhas, N. L. Rodrigues, C. C. Verotti, I. Cecconello, S. B. Heymsfield, and D. L. Waitzberg. 2009. Resting energy expenditure in white and non-white severely obese women. *Nutrición Hospitalaria* 24(6):676-681.

Morrison, J. A., M. P. Alfaro, P. Khoury, B. B. Thornton, and S. R. Daniels. 1996. Determinants of resting energy expenditure in young black girls and young white girls. *Journal of Pediatrics* 129(5):637-642.

Mortensen, S. J., I. Beeram, J. Florance, K. Momenzadeh, A. Mohamadi, E. K. Rodriguez, A. von Keudell, and A. Nazarian. 2021. Modifiable lifestyle factors associated with fragility hip fracture: A systematic review and meta-analysis. *Journal of Bone & Mineral Metabolism* 39(5):893-902.

Most, J., L. A. Gilmore, A. D. Altazan, M. St Amant, R. A. Beyl, E. Ravussin, and L. M. Redman. 2018. Propensity for adverse pregnancy outcomes in African-American women may be explained by low energy expenditure in early pregnancy. *American Journal of Clinical Nutrition* 107(6):957-964.

Nielsen, S. B., J. J. Reilly, M. S. Fewtrell, S. Eaton, J. Grinham, and J. C. K. Wells. 2011. Adequacy of milk intake during exclusive breastfeeding: A longitudinal study. *Pediatrics* 128(4):e907-914.

Nielsen, S. B., J. C. K. Wells, M. S. Fewtrell, S. Eaton, J. Grinham, and J. J. Reilly. 2013. Validation of energy requirement references for exclusively breast-fed infants. *British Journal of Nutrition* 109(11):2036-2043.

Nunes, C. L., F. Jesus, R. Francisco, C. N. Matias, M. Heo, S. B. Heymsfield, A. Bosy-Westphal, L. B. Sardinha, P. Martins, C. S. Minderico, and A. M. Silva. 2021. Adaptive thermogenesis after moderate weight loss: Magnitude and methodological issues. *European Journal of Nutrition* 61(3):1405-1416.

Nunes, C. L., N. Casanova, R. Francisco, A. Bosy-Westphal, M. Hopkins, L. B. Sardinha, and A. M. Silva. 2022. Does adaptive thermogenesis occur after weight loss in adults? A systematic review. *British Journal of Nutrition* 127(3):451-469.

Nymo, S., S. R. Coutinho, J. F. Rehfeld, H. Truby, B. Kulseng, and C. Martins. 2019. Physiological predictors of weight regain at 1-year follow-up in weight-reduced adults with obesity. *Obesity (Silver Spring)* 27(6):925-931.

O'Driscoll, R., J. Turicchi, K. Beaulieu, S. Scott, J. Matu, K. Deighton, G. Finlayson, and J. Stubbs. 2020. How well do activity monitors estimate energy expenditure? A systematic review and meta-analysis of the validity of current technologies. *British Journal of Sports Medicine* 54(6):332-340.

Okereke, N. C., L. Huston-Presley, S. B. Amini, S. Kalhan, and P. M. Catalano. 2004. Longitudinal changes in energy expenditure and body composition in obese women with normal and impaired glucose tolerance. *American Journal of Physiology, Endocrinology, and Metabolism* 287(3):E472-E479.

Olivier, N., F. A. Wenhold, and P. Becker. 2016. Resting energy expenditure of black overweight women in South Africa is lower than of white women. *Annals of Nutrition and Metabolism* 69(1):24-30.

O'Sullivan, D. E., R. L. Sutherland, S. Town, K. Chow, J. Fan, N. Forbes, S. J. Heitman, R. J. Hilsden, and D. R. Brenner. 2022. Risk factors for early-onset colorectal cancer: A systematic review and meta-analysis. *Clinical Gastroenterology and Hepatology* 20(6):1229-1240, e1225.

Park, M. Y., J. Kim, N. Chung, H. Y. Park, H. Hwang, J. S. Han, J. M. So, C. H. Lee, J. Park, and K. Lim. 2020. Dietary factors and eating behaviors affecting diet-induced thermogenesis in obese individuals: A systematic review. *Journal of Nutritional Science and Vitaminology* 66(1):1-9.

Pereira, L. C. R., S. A. Purcell, S. A. Elliott, L. J. McCargar, R. C. Bell, P. J. Robson, C. M. Prado, and the ENRICH Study. 2019. The use of whole body calorimetry to compare measured versus predicted energy expenditure in postpartum women. *American Journal of Clinical Nutrition* 109(3):554-565.

Pisanu, S., A. Deledda, A. Loviselli, I. Huybrechts, and F. Velluzzi. 2020. Validity of accelerometers for the evaluation of energy expenditure in obese and overweight individuals: A systematic review. *Journal of Nutrition and Metabolism* 2020.

Plachta-Danielzik, S., B. Landsberg, A. Bosy-Westphal, M. Johannsen, D. Lange, and M. J Muller. 2008. Energy gain and energy gap in normal-weight children: Longitudinal data of the KOPS. *Obesity (Silver Spring, Md.)* 16(4):777-783.

Plasqui, G., A. G. Bonomi, and K. R. Westerterp. 2013. Daily physical activity assessment with accelerometers: New insights and validation studies. *Obesity Reviews* 14(6):451-462.

Pretorius, A., P. Wood, P. Becker, and F. Wenhold. 2021. Resting energy expenditure and related factors in 6- to 9-year-old southern African children of diverse population groups. *Nutrients* 13(6).

Quatela, A., R. Callister, A. Patterson, and L. Macdonald-Wicks. 2016. The energy content and composition of meals consumed after an overnight fast and their effects on diet induced thermogenesis: A systematic review, meta-analyses and meta-regressions. *Nutrients* 8(11).

Reilly, J. J., S. Ashworth, and J. C. K. Wells. 2005. Metabolisable energy consumption in the exclusively breast-fed infant aged 3--6 months from the developed world: A systematic review. *British Journal of Nutrition* 94(1):56-63.

Reneau, J., B. Obi, A. Moosreiner, and S. Kidambi. 2019. Do we need race-specific resting metabolic rate prediction equations? *Nutrition Diabetes* 9(1):21.

Rexrode, K. M., J. E. Buring, and J. E. Manson. 2001. Abdominal and total adiposity and risk of coronary heart disease in men. *International Journal of Obesity and Related Metabolic Disorders* 25(7):1047-1056.

Rush, E. C., L. D. Plank, and S. M. Robinson. 1997. Resting metabolic rate in young Polynesian and Caucasian women. *International Journal of Obesity and Related Metabolic Disorders* 21(11):1071-1075.

Rush, E. C., L. D. Plank, P. S. Davies, P. Watson, and C. R. Wall. 2003. Body composition and physical activity in New Zealand Maori, Pacific and European children aged 5-14 years. *British Journal of Nutrition* 90(6):1133-1139.

Saad, M. F., S. A. Alger, F. Zurlo, J. B. Young, C. Bogardus, and E. Ravussin. 1991. Ethnic differences in sympathetic nervous system-mediated energy expenditure. *American Journal of Physiology* 261(6 Pt 1):E789-E794.

Santa-Clara, H., L. Szymanski, T. Ordille, and B. Fernhall. 2006. Effects of exercise training on resting metabolic rate in postmenopausal African American and Caucasian women. *Metabolism* 55(10):1358-1364.

Savard, C., A. Lebrun, S. O'Connor, B. Fontaine-Bisson, F. Haman, and A. S. Morisset. 2021. Energy expenditure during pregnancy: A systematic review. *Nutrition Reviews* 79(4):394-409.

Schwartz, A., and E. Doucet. 2010. Relative changes in resting energy expenditure during weight loss: A systematic review. *Obesity Reviews* 11(7):531-547.

Schwartz, A., J. L. Kuk, G. Lamothe, and E. Doucet. 2012. Greater than predicted decrease in resting energy expenditure and weight loss: Results from a systematic review. *Obesity (Silver Spring)* 20(11):2307-2310.

Sharifzadeh, M., M. Bagheri, J. R. Speakman, and K. Djafarian. 2021. Comparison of total and activity energy expenditure estimates from physical activity questionnaires and doubly labelled water: A systematic review and meta-analysis. *British Journal of Nutrition* 125(9):983-997.

Sharma, V., S. Coleman, J. Nixon, L. Sharples, J. Hamilton-Shield, H. Rutter, and M. Bryant. 2019. A systematic review and meta-analysis estimating the population prevalence of comorbidities in children and adolescents aged 5 to 18 years. *Obesity Reviews* 20(10):1341-1349.

Sharp, T. A., M. L. Bell, G. K. Grunwald, K. H. Schmitz, S. Sidney, C. E. Lewis, K. Tolan, and J. O. Hill. 2002. Differences in resting metabolic rate between white and African-American young adults. *Obesity Research* 10(8):726-732.

Shook, R. P., G. A. Hand, X. Wang, A. E. Paluch, R. Moran, J. R. Hébert, D. L. Swift, C. J. Lavie, and S. N. Blair. 2014. Low fitness partially explains resting metabolic rate differences between African American and white women. *American Journal of Medicine* 127(5):436-442.

Soares, M. J., L. S. Piers, K. O'Dea, and P. S. Shetty. 1998. No evidence for an ethnic influence on basal metabolism: An examination of data from India and Australia. *British Journal of Nutrition* 79(4):333-341.

Sohn, W., H. W. Lee, S. Lee, J. H. Lim, M. W. Lee, C. H. Park, and S. K. Yoon. 2021. Obesity and the risk of primary liver cancer: A systematic review and meta-analysis. *Clinical and Molecular Hepatology* 27(1):157-174.

Song, L. L., K. Venkataraman, P. Gluckman, Y. S. Chong, M. W. Chee, C. M. Khoo, M. K. Leow, Y. S. Lee, E. S. Tai, and E. Y. Khoo. 2016. Smaller size of high metabolic rate organs explains lower resting energy expenditure in Asian-Indian than Chinese men. *International Journal of Obesity (London)* 40(4):633-638.

Spaeth, A. M., D. F. Dinges, and N. Goel. 2015. Resting metabolic rate varies by race and by sleep duration. *Obesity (Silver Spring)* 23(12):2349-2356.

Spurr, G. B., J. C. Reina, and R. G. Hoffmann. 1992. Basal metabolic rate of Colombian children 2-16 y of age: Ethnicity and nutritional status. *American Journal of Clinical Nutrition* 56(4):623-629.

Sun, J., B. Xi, L. Yang, M. Zhao, M. Juonala, and C. G. Magnussen. 2021. Weight change from childhood to adulthood and cardiovascular risk factors and outcomes in adulthood: A systematic review of the literature. *Obesity Reviews* 22(3).

Sun, M., B. A. Gower, T. R. Nagy, C. A. Trowbridge, C. Dezenberg, and M. I. Goran. 1998. Total, resting, and activity-related energy expenditures are similar in Caucasian and African-American children. *American Journal of Physiology* 274(2):E232-E237.

Sun, M., B. A. Gower, A. A. Bartolucci, G. R. Hunter, R. Figueroa-Colon, and M. I. Goran. 2001. A longitudinal study of resting energy expenditure relative to body composition during puberty in African American and white children. *American Journal of Clinical Nutrition* 73(2):308-315.

Tanaka, C., J. J. Reilly, and W. Y. Huang. 2014. Longitudinal changes in objectively measured sedentary behaviour and their relationship with adiposity in children and adolescents: Systematic review and evidence appraisal. *Obesity Reviews* 15(10):791-803.

Tershakovec, A. M., K. M. Kuppler, B. Zemel, and V. A. Stallings. 2002. Age, sex, ethnicity, body composition, and resting energy expenditure of obese African American and white children and adolescents. *American Journal of Clinical Nutrition* 75(5):867-871.

Thakkar, S. K., F. Giuffrida, C. H. Cristina, C. A. De Castro, R. Mukherjee, L. A. Tran, P. Steenhout, L. Y. Lee, and F. Destaillats. 2013. Dynamics of human milk nutrient composition of women from Singapore with a special focus on lipids. *American Journal of Human Biology* 25(6):770-779.

Tranah, G. J., T. M. Manini, K. K. Lohman, M. A. Nalls, S. Kritchevsky, A. B. Newman, T. B. Harris, I. Miljkovic, A. Biffi, S. R. Cummings, and Y. Liu. 2011. Mitochondrial DNA variation in human metabolic rate and energy expenditure. *Mitochondrion* 11(6):855-861.

Tudor-Locke, C., J. E. Williams, J. P. Reis, and D. Pluto. 2002. Utility of pedometers for assessing physical activity: Convergent validity. *Sports Medicine* 32(12):795-808.

Tugault-Lafleur, C. N., J. L. Black, and S. I. Barr. 2017. A systematic review of methods to assess children's diets in the school context. *Advances in Nutrition* 8(1):63-79.

Turicchi, J., R. O'Driscoll, G. Finlayson, K. Beaulieu, K. Deighton, and R. J. Stubbs. 2019. Associations between the rate, amount, and composition of weight loss as predictors of spontaneous weight regain in adults achieving clinically significant weight loss: A systematic review and meta-regression. *Obesity Reviews* 20(7):935-946.

Vander Weg, M. W., R. C. Klesges, and K. D. Ward. 2000. Differences in resting energy expenditure between black and white smokers: Implications for postcessation weight gain. *European Journal of Clinical Nutrition* 54(12):895-899.

Vander Weg, M. W., J. M. Watson, R. C. Klesges, L. H. Eck Clemens, D. L. Slawson, and B. S. McClanahan. 2004. Development and cross-validation of a prediction equation for estimating resting energy expenditure in healthy African-American and European-American women. *European Journal of Clinical Nutrition* 58(3):474-480.

Walsh, M. C., G. R. Hunter, B. Sirikul, and B. A. Gower. 2004. Comparison of self-reported with objectively assessed energy expenditure in black and white women before and after weight loss. *American Journal of Clinical Nutrition* 79(6):1013-1019.

Wang, C., W. Fu, S. Cao, H. Jiang, Y. Guo, H. Xv, J. Liu, Y. Gan, and Z. Lu. 2021. Weight loss and the risk of dementia: A meta-analysis of cohort studies. *Current Alzheimer Research* 18(2):125-135.

Wang, X., T. You, L. Lenchik, and B. J. Nicklas. 2010. Resting energy expenditure changes with weight loss: Racial differences. *Obesity (Silver Spring)* 18(1):86-91.

Wehling, H., and J. Lusher. 2019. People with a body mass index 30 under-report their dietary intake: A systematic review. *Journal of Health Psychology* 24(14):2042-2059.

Weinsier, R. L., G. R. Hunter, P. A. Zuckerman, D. T. Redden, B. E. Darnell, D. E. Larson, B. R. Newcomer, and M. I. Goran. 2000. Energy expenditure and free-living physical activity in black and white women: Comparison before and after weight loss. *American Journal of Clinical Nutrition* 71(5):1138-1146.

Wells, J. C., and P. S. Davies. 1998. Estimation of the energy cost of physical activity in infancy. *Archives of Disease in Childhood* 78(2):131-136.

Weyer, C., S. Snitker, R. Rising, C. Bogardus, and E. Ravussin. 1999. Determinants of energy expenditure and fuel utilization in man: Effects of body composition, age, sex, ethnicity and glucose tolerance in 916 subjects. *International Journal of Obesity and Related Metabolic Disorders* 23(7):715-722.

Wong, W. W., N. F. Butte, A. C. Hergenroeder, R. B. Hill, J. E. Stuff, and E. O. Smith. 1996. Are basal metabolic rate prediction equations appropriate for female children and adolescents? *Journal of Applied Physiology (1985)* 81(6):2407-2414.

Wong, W. W., N. F. Butte, K. J. Ellis, A. C. Hergenroeder, R. B. Hill, J. E. Stuff, and E. O. Smith. 1999. Pubertal African-American girls expend less energy at rest and during physical activity than Caucasian girls. *Journal of Clinical Endocrinology and Metabolism* 84(3):906-911.

Wouters-Adriaens, M. P., and K. R. Westerterp. 2008. Low resting energy expenditure in Asians can be attributed to body composition. *Obesity (Silver Spring)* 16(10):2212-2216.

Wycherley, T. P., L. J. Moran, P. M. Clifton, M. Noakes, and G. D. Brinkworth. 2012. Effects of energy-restricted high-protein, low-fat compared with standard-protein, low-fat diets: A meta-analysis of randomized controlled trials. *American Journal of Clinical Nutrition* 96(6):1281-1298.

Xiao, C. M., Y. Zhang, Q. Chen, X. Q. Zhang, X. F. Li, R. Y. Shao, and Y. M. Gao. 2021. Factors associated with gestational diabetes mellitus: A meta-analysis. *Journal of Diabetes Research* 2021.

Yanovski, S. Z., J. C. Reynolds, A. J. Boyle, and J. A. Yanovski. 1997. Resting metabolic rate in African-American and Caucasian girls. *Obesity Research* 5(4):321-325.

Youssef, M. R., A. S. C. Reisner, A. S. Attia, M. H. Hussein, M. Omar, A. LaRussa, C. A. Galvani, M. Aboueisha, M. Abdelgawad, E. A. Toraih, G. W. Randolph, and E. Kandil. 2021. Obesity and the prevention of thyroid cancer: Impact of body mass index and weight change on developing thyroid cancer - pooled results of 24 million cohorts. *Oral Oncology* 112:105085.

Yu, H. J., M. Ho, X. Liu, J. Yang, P. H. Chau, and D. Y. T. Fong. 2022. Association of weight status and the risks of diabetes in adults: A systematic review and meta-analysis of prospective cohort studies. *International Journal of Obesity (London)* 46(6):1101-1113.

Zhang, X., J. Rhoades, B. J. Caan, D. E. Cohn, R. Salani, S. Noria, A. A. Suarez, E. D. Paskett, and A. S. Felix. 2019. Intentional weight loss, weight cycling, and endometrial cancer risk: A systematic review and meta-analysis. *International Journal of Gynecology and Cancer* 29(9):1361-1371.

Zhang, Y., C. M. Xiao, Y. Zhang, Q. Chen, X. Q. Zhang, X. F. Li, R. Y. Shao, and Y. M. Gao. 2021. Factors associated with gestational diabetes mellitus: A meta-analysis. *Journal of Diabetes Research* 2021:6692695.

Zhou, W., Y. Shi, Y. Q. Li, Z. Ping, C. Wang, X. Liu, J. Lu, Z. X. Mao, J. Zhao, L. Yin, D. Zhang, Z. Tian, L. Zhang, and L. Li. 2018. Body mass index, abdominal fatness, and hypertension incidence: A dose-response meta-analysis of prospective studies. *Journal of Human Hypertension* 32(5):321-333.

Zou, H., P. Yin, L. Liu, W. Liu, Z. Zhang, Y. Yang, W. Li, Q. Zong, and X. Yu. 2019. Body-weight fluctuation was associated with increased risk for cardiovascular disease, all-cause and cardiovascular mortality: A systematic review and meta-analysis. *Frontiers in Endocrinology* 10.

Zou, H., P. Yin, L. Liu, W. Duan, P. Li, Y. Yang, W. Li, Q. Zong, and X. Yu. 2021. Association between weight cycling and risk of developing diabetes in adults: A systematic review and meta-analysis. *Journal of Diabetes Investigation* 12(4):625-632.

Appendix K

Interview Processes Used in National Surveys

NHANES

In National Health and Nutrition Examination Survey (NHANES), anthropometric measurements are collected by trained health technicians during the health examination in the mobile examination clinic (MEC), using standardized procedures (CDC, 2011). In the health examination, measured height and weight are recorded and are used to calculate body mass index (BMI) defined as the weight in kilograms divided by the square of the height in meters. BMI is used to categorize weight status in adults (≥ 19 years) and children (< 19 years).

For children, BMI percentiles are used to classify underweight (< 5th), healthy (5 to ≤ 85th), overweight (85th to ≤ 95th), and obese (> 95th). For adults, percentiles are not used, and BMI is used to define underweight (< 18.5), normal weight (≥ 18.5 and ≤ 25), overweight (> 25 and ≤ 30) and obese (> 30). Obesity is further categorized into classes: class I (30 to < 35), class II (35 to < 40), and class III (≥ 40) (CDC, 2011).

Waist circumference is measured in a standing position, directly above the iliac crest, and recorded to the nearest millimeter, using a steel measuring tape. Precisely, participants are instructed by the technician to cross their arms and place their hands on their opposite shoulders. The technician then locates and marks the uppermost lateral border of the right ilium at the midaxillary line and measures the waist circumference. The technician places the measuring tape at the marking on the midaxillary line and wraps it around the waist, making sure that the tape is aligned horizontally. This is done by double-checking that it is parallel to the floor and does not compress the waist or abdomen; the technician then records the measurement to the nearest millimeter (CDC, 2011).

Sagittal abdominal diameter (SAD) is measured in the supine position on the MEC examination table; trained NHANES technicians use an abdominal caliper to determine the external distance from the front of the abdomen to the small of the participant's back at the iliac level line. More specifically, the participant is first positioned on the table with their knees bent, feet resting flat on the examination table, and arms crossed at the chest. The technician then locates the right iliac crest and marks the point at which it intersects with the midaxillary line, and then completes the same steps for the left iliac crest. After doing so, the iliac level line is able to be identified and marked in preparation for SAD measurement. The technician completes a minimum of two SAD measurements using an appropriately sized abdominal caliper. To complete a measurement, the technician asks the participant to raise his or her hips so the technician can insert the lower arm of the caliper under the small of the participant's back. The technician checks to ensure that the lower arm of the caliper contacts the small of the participant's back, grasps the caliper shaft with one hand, and slides the upper arm of the caliper down to ~2 centimeters above the abdomen with the other hand, making sure that the edge of the caliper is aligned with the mark at the iliac level line (CDC, 2011).

As outlined in the NHANES procedures manual (CDC, 2011), the participant is instructed by the technician to "slowly take in a gentle breath, slowly let the air out, and then pause" so the technician can slowly lower the upper arm of the caliper down onto the abdomen without compressing it and take the SAD measurement while the participant is in a resting state. The same process is repeated for any additional SAD measurements.

The dietary data collected in NHANES is provided as the U.S. Department of Agriculture (USDA) What We Eat in America survey. A 24-hour recall (24HR) is collected, first in-person in a MEC and then over the phone, approximately 3–10 days later, with trained interviewers using the Automated Multiple-Pass Method (AMPM; Blanton et al., 2006; Moshfegh et al., 2008). Participants are asked to report all foods and beverages consumed over the previous 24 hours (i.e., midnight to midnight the previous day) using the AMPM five-step process. The 24HRs are completed by the participant or their proxy, according to the age of the participant, in the following manner: children 2 to 5 years have a proxy; children 6 to 8 years have a proxy and provide assistance; children 9 to 11 years complete the 24HR with proxy assistance; and children and adults ≥12 years complete the 24HR individually. All recorded foods, beverages, and other food components are then converted to their energy value using the USDA Food and Nutrient Database for Dietary Studies (USDA, 2019).

Canadian Health Measures Survey-Nutrition

In the Canadian Health Measures Survey (CHMS) participants are first asked to complete the height (standing and sitting) and weight measurements using a Proscale 200 stadiometer (Accurate Technology Inc., Fletcher, NC), custom-built sitting height block with stadiometer, and Mettler Toledo scale with Panther Plus digit readout (Mettler Toledo Canada, Mississauga, ON), respectively. For height, participants remove their shoes, stand with their feet together, and keep the back side of their body in contact with the stadiometer as they look straight ahead and stand as "tall as possible." Participants are then asked to "take a deep breath in and hold it" while the trained technician records the standing height in both centimeters and millimeters. For anthropometry, physical measurements include height (sitting and standing), weight, waist circumference, hip circumference, as well as skinfold thickness at five different sites (i.e., triceps, biceps, subscapular, iliac crest, and calf) (Bryan et al., 2007; Tremblay et al., 2007). Apart from hip circumference, all anthropometric measurements are collected in accordance with the *Canadian Physical Activity, Fitness, and Lifestyle Approach Manual* (Canadian Society for Exercise Physiology, 2003). For hip circumference, measurements are taken based on the Canadian Standardized Test of Fitness (CSTF, 1986). Weight status categories for children and adults are categorized as described above using the same classifications as NHANES.

Canadian Community Health Survey

In the 2015 CCHS-Nutrition, a household member is randomly selected and asked to complete a questionnaire on the demographics, health status, and lifestyle of the household, as well as a 24HR on either a weekend day or weekday to assess the dietary intakes of the selected individual over the previous 24 hours (Health Canada, 2017). During the 24 hours, participants are asked to provide detailed information on all foods consumed, including the type, time, and location of the eating occasion, as well as the weight or size of the portion consumed.

The 24HR is computer assisted and administered by trained interviewers in the home, using a Canadian modification of the USDA's AMPM (Blanton et al., 2006). Depending on the age of the participant, some 24HRs are completed via proxy or are proxy-assisted. For example for children 1 to 5 years, the 24HR is completed by a parent or guardian proxy; for children 6 to 11 years, the 24HR is completed by the respondent, but is proxy-assisted by a parent or guardian; and for children and adults 12 years and older, the 24HR is completed by the respondent (Blanton et al., 2006).

Energy and nutrient values derived from food and beverage intake are calculated using Health Canada's Canadian Nutrient File (version 2015) (Health Canada, 2021). In the most recent survey, approximately 20,487 CCHS-Nutrition participants completed the initial in-person 24HR in the 2015 cycle; an additional 35 percent of the main sample were randomly selected to complete a second dietary recall via telephone approximately 3 to 10 days after completion of the initial recall on a different day of the week. Participants were provided with a *Food Model Booklet* to help facilitate food recall and portion size estimation during the second 24HR. The response rates for the two 24HRs were 61.6 percent and 68.6 percent, respectively (Health Canada, 2017).

REFERENCES

Blanton, C.A., A. J. Moshfegh, D. J. Baer, and M. J. Kretsch. 2006. The USDA Automated Multiple-Pass Method accurately estimates group total energy and nutrient intake. *Journal of Nutrition* 136(10):2594-2599. doi: 10.1093/jn/136.10.2594. PMID: 16988132.

Bryan, S., M. St-Denis, and D. Wojtas. 2007. Canadian Health Measures Survey: Clinic operations and logistics. *Health Report* 18(Suppl):53-70.

Canadian Society for Exercise Physiology. 2003. *Canadian physical activity, fitness and lifestyle approach manual*. https://edisciplinas.usp.br/pluginfile.php/4114941/mod_resource/content/1/THE%20CANADIAN%20PHYSICAL%20ACTIVITY%2C%20FITNESS%20AND%20LIFESTYLE%20APPROACH%20%E2%80%A2%20THIRD%20ED.%20SUPPLEMENT.pdf (accessed November 27, 2022).

CSTF (Canadian Standardized Test of Fitness). 1986. *Operations manual*. 3rd ed. Ottawa, Ontario: Government of Canada, Fitness and Amateur Sport

CDC (Centers for Disease Control and Prevention). 2011. *National Health and Nutrition Examination Survey (NHANES) anthropometry procedures manual*. https://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/Anthropometry_Procedures_Manual.pdf (accessed November 27, 2022).

Health Canada. 2017. *Reference guide to understanding and using the data - 2015 Canadian Community Health Survey-Nutrition*. https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/reference-guide-understanding-using-data-2015.html (accessed November 27, 2022).

Health Canada. 2021. *Health Canada's Canadian nutrient file (CNF)*. https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp (accessed November 27, 2022).

Moshfegh, A.J., D. G. Rhodes, D. J. Baer, T. Murayi, J. C. Clemens, W. V. Rumpler, D. R. Paul, R. S. Sebastian, K. J. Kuczynski, L. A. Ingwersen, R. C. Staples, and L. E. Cleveland. 2008. The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. *American Journal of Clinical Nutrition* 88(2):324-332.

Tremblay, M., M. Wolfson, and S. Connor Gorber. 2007. Canadian Health Measures Survey: Rationale, background and overview. *Health Report* 18(Suppl):7-20.

USDA (U.S. Department of Agriculture). 2019. *Food and nutrient database for dietary studies (FNDDS)*. https://data.nal.usda.gov/dataset/food-and-nutrient-database-dietary-studies-fndds (accessed November 27, 2022).

Appendix L

National Survey Data from the United States and Canada

CONTENTS

TABLE L-1 Body Measurement Summary Statistics, Boys 18 Years of Age and Younger, NHANES, 2015–2018

					Percentiles						
Measure	Age (y)	k	Mean	SE	5th	10th	25th	50th	75th	90th	95th
Body mass index (calculated as kg/m^2)	2–3 y	388	16.8	0.2	14.5	14.8	15.7	16.4	17.4	18.8	19.8
	4–8 y	936	17.1	0.1	13.9	14.5	15.2	16.2	17.9	20.8	23.0
	9–13 y	872	20.6	0.2	14.9	15.5	16.7	19.2	23.3	27.7	30.6
	14–18 y	768	24.0	0.3	16.9	17.7	19.8	22.3	26.6	32.3	35.8
Weight (kg)	0–6 mo	186	6.7	0.1	4.1	4.6	5.5	6.7	7.8	8.6	9.1
	7–11 mo	147	9.4	0.1	7.7	8.1	8.6	9.3	10.0	10.7	11.3
	1–3 y	694	14.0	0.2	9.7	10.4	11.8	13.6	15.5	17.6	19.2
	4–8 y	939	25.0	0.4	16.3	17.3	19.8	23.1	28.4	35.4	39.8
	9–13 y	873	46.7	0.6	27.4	29.1	34.2	43.3	54.9	68.3	80.5
	14–18 y	768	72.1	1.0	47.1	50.9	58.6	66.7	81.5	96.4	114.5
Height (cm)	0–6 mo	186	61.7	0.4	52.8	54.1	57.6	62.7	65.8	67.9	69.0
Length for < 2 y	7–11 mo	147	72.1	0.3	67.3	68.4	69.8	71.9	73.9	75.5	76.5
	12–23 mo	265	81.3	0.3	73.7	75.3	78.0	81.1	84.4	88.0	89.3
	2–3 y	389	95.5	0.3	85.8	88.1	90.9	95.6	99.8	102.8	105.0
	4–8 y	936	119.9	0.5	102.2	105.1	111.4	120.2	128.1	134.2	137.4
	9–13 y	872	149.0	0.5	130.3	134.2	139.7	148.3	157.7	166.3	169.5
	14–18 y	768	172.9	0.3	159.4	162.7	167.8	173.3	178.6	182.3	185.0

continued

TABLE L-1 Continued

				Percentiles							
Measure	Age (y)	k	Mean	SE	5th	10th	25th	50th	75th	90th	95th
Waist circumference (cm)	2–3 y	338	50.1	0.5	44.4	45.2	47.1	49.4	52.0	54.3	57.1
	4–8 y	883	58.1	0.4	48.8	50.1	52.4	56.0	60.8	70.1	75.3
	9–13 y	840	72.8	0.6	55.9	58.0	61.6	69.2	80.9	94.3	100.1
	14–18 y	752	83.4	0.8	65.4	67.0	71.5	78.4	90.8	107.0	116.3
Average sagittal abdominal diameter (cm)*	9–13 y	446	16.3	0.2	12.5	13.0	13.9	15.4	17.9	20.6	22.3
	14–18 y	400	18.5	0.3	14.2	14.8	15.9	17.4	19.9	24.0	27.2
Waist–hip ratio**	12-13 y	140	0.87	0.01	0.78	0.79	0.81	0.85	0.91	0.98	1.00
	14-18 y	352	0.86	0.01	0.77	0.78	0.80	0.84	0.89	0.97	1.00

NOTE: cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018; *2015–2016; **2017–2018.

TABLE L-2 Body Measurement Summary Statistics, Girls 18 Years of Age and Younger, NHANES, 2015–2018

					Percentiles						
Measure	Age (y)	k	Mean	SE	5th	10th	25th	50th	75th	90th	95th
Body mass index (calculated as kg/m²)	2–3 y	367	16.3	0.1	14.2	14.6	15.3	16.1	17.0	17.9	18.6
	4–8 y	934	17.1	0.1	13.7	14.2	15.0	16.2	18.2	21.1	23.2
	9–13 y	898	20.7	0.2	15.0	15.7	17.0	19.5	23.6	27.9	30.1
	14–18 y	755	24.9	0.3	18.0	18.9	20.6	23.2	27.7	32.8	37.5
Weight (kg)	0–6 mo	191	6.2	0.1	4.1	4.4	5.1	6.0	7.3	7.9	8.1
	7–11 mo	148	8.7	0.1	6.8	7.3	7.9	8.6	9.5	10.3	10.5
	1–3 y	634	13.2	0.1	9.5	9.9	11.1	13.0	14.6	16.6	17.7
	4–8 y	934	24.1	0.3	15.6	16.6	18.8	22.2	26.9	34.3	39.6
	9–13 y	899	46.5	0.7	27.1	29.2	34.4	43.8	55.0	66.9	73.6
	14–18 y	755	65.4	0.8	45.4	47.8	53.3	61.2	72.9	87.6	98.8
Height (cm)	0–6 mo	191	60.5	0.3	52.9	54.3	56.4	60.3	64.6	66.8	67.6
Length for < 2 y	7–11 mo	148	70.4	0.3	65.6	66.5	68.3	70.4	72.3	74.3	75.6
	12–23 mo	229	80.6	0.4	73.5	75.1	77.4	80.2	83.4	86.7	88.2
	2–3 y	368	93.7	0.5	84.8	86.0	89.4	93.7	97.2	101.1	103.9
	4–8 y	935	117.5	0.4	101.0	103.3	109.4	117.6	124.9	130.9	134.2
	9–13 y	898	148.4	0.6	130.0	133.6	140.3	149.1	156.7	161.5	164.3
	14–18 y	755	162.0	0.4	151.2	153.5	157.4	161.6	166.4	170.6	173.0

continued

TABLE L-2 Continued

Measure	Age (y)	k	Mean	SE	Percentiles						
					5th	10th	25th	50th	75th	90th	95th
Waist circumference (cm)	2–3 y	319	49.2	0.2	43.1	44.6	46.6	49.4	51.2	53.6	55.1
	4–8 y	883	57.8	0.3	48.2	49.5	52.0	55.2	61.0	69.8	76.8
	9–13 y	864	72.5	0.5	55.9	58.5	62.8	70.1	80.0	90.7	96.9
	14–18 y	728	82.5	0.7	66.7	68.8	72.9	79.0	89.0	100.2	109.2
Average sagittal abdominal diameter (cm)*	9–13 y	453	16.2	0.2	12.1	12.8	14.0	15.5	17.8	20.3	21.7
	14–18 y	383	18.4	0.2	14.3	14.7	15.8	17.6	20.1	22.7	25.0
Waist–hip ratio**	12-13 y	128	0.84	0.01	0.74	0.76	0.79	0.83	0.86	0.92	0.95
	14-18 y	343	0.83	0.01	0.73	0.76	0.78	0.82	0.86	0.91	0.95

NOTES: cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. Pregnant and lactating adolescents excluded.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018; *2015–2016; **2017–2018.

TABLE L-3 Body Measurement Summary Statistics, Men 19 Years of Age and Older, NHANES, 2015–2018

Measure	Age (y)	k	Mean	SE	Percentiles								
					Min	Max	5th	10th	25th	50th	75th	90th	95th
Body mass index (calculated as kg/m^2)	19–30	1,005	27.8	0.4	15.7	62.0	18.7	20.3	22.7	26.5	31.7	36.7	39.6
	31–50	1,581	30.2	0.3	15.1	86.2	21.8	23.2	25.8	29.1	33.3	38.5	42.1
	51–70	1,807	29.7	0.2	14.9	57.4	22.0	22.9	25.5	28.9	33.0	37.0	41.1
	> 70	818	28.7	0.2	16.6	56.0	20.8	22.4	25.3	28.0	31.9	35.2	36.8
	19+	5,211	29.4	0.2	14.9	86.2	20.8	22.3	25.0	28.4	32.7	37.1	41.0
Weight (kg)	19–30	1,006	86.0	1.3	39.2	191.4	58.4	61.6	69.8	81.4	98.2	116.0	128.2
	31–50	1,582	94.1	0.8	46.2	242.6	65.2	69.8	78.6	89.9	104.5	123.3	137.4
	51–70	1,810	91.1	0.7	36.8	192.3	63.2	68.2	76.6	88.7	102.3	117.1	129.2
	> 70	822	85.1	0.9	43.7	170.8	58.7	63.1	72.8	83.3	96.8	107.1	115.7
	19+	5,220	90.4	0.6	36.8	242.6	61.6	66.3	75.2	87.2	101.8	119.1	130.2
Height (cm)	19–30	1,006	175.8	0.3	136.5	198.4	164.3	167.0	171.0	176.1	180.4	184.9	186.8
	31–50	1,584	176.3	0.3	149.6	202.7	163.5	166.5	171.4	176.4	181.3	185.7	188.5
	51–70	1,810	174.8	0.3	140.1	197.7	162.5	164.9	169.5	174.9	179.7	184.2	187.2
	> 70	827	172.0	0.4	149.2	193.1	160.1	163.1	167.4	172.2	177.0	180.8	183.4
	19+	5,227	175.3	0.2	136.5	202.7	162.8	165.7	170.2	175.4	180.2	184.7	187.3

continued

TABLE L-3 Continued

Measure	Age (y)	k	Mean	SE	Percentiles								
					Min	Max	5th	10th	25th	50th	75th	90th	95th
Waist circumference (cm)	19–30	983	94.5	1.0	62.3	161.6	72.4	75.6	81.4	91.0	105.7	117.9	127.8
	31–50	1,527	103.5	0.6	67.2	162.7	81.0	85.1	92.5	101.4	111.6	125.3	133.0
	51–70	1,751	106.0	0.7	65.9	169.6	83.8	88.7	95.7	104.3	114.8	125.8	135.4
	> 70	754	106.4	0.7	67.6	156.1	84.6	89.3	97.8	105.5	114.9	123.7	129.9
	19+	5,015	102.6	0.5	62.3	169.6	77.3	82.5	91.4	101.6	111.8	123.9	132.5
Average sagittal abdominal diameter (cm)*	19–30	523	21.4	0.2	14.4	38.1	16.0	16.8	18.1	20.5	23.8	27.1	29.9
	31–50	816	23.6	0.3	13.6	40.8	17.4	18.5	20.6	23.0	25.9	29.7	31.4
	51–70	834	24.2	0.3	14.5	39.9	17.7	19.3	21.2	23.6	26.8	29.6	31.8
	> 70	344	24.4	0.3	13.7	38.3	18.7	19.9	21.7	24.2	26.9	29.3	30.7
	19+	2,517	23.4	0.2	13.6	40.8	17.0	18.0	20.2	22.8	25.9	29.4	31.2
Waist–hip ratio**	19–30	457	0.91	0.01	0.73	1.12	0.80	0.82	0.86	0.90	0.96	1.01	1.04
	31–50	705	0.97	0.00	0.80	1.24	0.85	0.88	0.92	0.96	1.01	1.05	1.07
	51–70	902	1.01	0.01	0.77	1.19	0.90	0.92	0.96	1.00	1.05	1.08	1.10
	> 70	400	1.01	0.00	0.84	1.19	0.90	0.94	0.97	1.01	1.04	1.08	1.10
	19+	2,464	0.97	0.00	0.73	1.24	0.84	0.87	0.92	0.97	1.02	1.06	1.08

NOTE: cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018; *2015–2016; **2017–2018.

TABLE L-4 Body Measurement Summary Statistics, Women 19 Years of Age and Older, NHANES, 2015–2018

					Percentiles								
Measure	Age (y)	n	Mean	SE	Min	Max	5th	10th	25th	50th	75th	90th	95th
Body mass index (calculated as kg/m^2)	19–30	1,108	28.3	0.4	14.8	66.2	18.9	19.8	22.0	26.3	32.8	38.9	43.2
	31–50	1,806	30.5	0.3	15.7	65.8	20.4	21.7	24.2	28.7	34.8	42.4	46.4
	51–70	1,887	30.3	0.3	14.5	84.4	20.0	22.0	24.6	29.1	34.5	40.3	44.2
	> 70	820	29.0	0.3	14.2	63.6	20.5	21.6	24.7	28.3	32.2	36.6	40.1
	19+	5,621	29.8	0.2	14.2	84.4	19.7	21.2	23.9	28.3	33.9	40.2	44.4
Weight (kg)	19–30	1,108	74.7	1.0	36.2	181.0	49.0	51.7	58.6	69.6	86.1	105.6	116.3
	31–50	1,808	80.7	1.0	40.3	179.2	51.7	56.0	64.8	75.1	92.6	112.8	126.5
	51–70	1,890	78.3	0.8	38.5	219.6	49.6	55.7	64.3	74.7	89.4	103.8	116.9
	> 70	820	71.8	0.8	32.4	144.7	49.1	52.1	59.5	69.7	81.0	93.6	102.7
	19+	5,626	77.5	0.6	32.4	219.6	49.8	54.0	62.2	73.2	88.6	105.2	119.5
Height (cm)	19–30	1,108	162.5	0.3	139.9	185.2	151.1	153.9	158.0	162.6	166.9	170.9	173.3
	31–50	1,808	162.5	0.3	137.6	189.3	151.0	153.2	157.8	162.6	167.2	171.3	173.7
	51–70	1,888	160.9	0.3	138.3	187.8	150.0	152.8	156.1	160.8	165.5	169.6	171.4
	> 70	822	157.1	0.3	129.7	179.6	145.6	149.0	153.1	156.8	161.5	165.2	167.9
	19+	5,626	161.3	0.2	129.7	189.3	149.8	152.5	156.4	161.3	166.0	170.2	172.5

continued

TABLE L-4 Continued

Measure	Age (y)	n	Mean	SE	Percentiles								
					Min	Max	5th	10th	25th	50th	75th	90th	95th
Waist circumference (cm)	19–30	1,053	92.5	0.9	56.4	171.6	70.0	72.1	78.0	89.4	103.8	118.6	125.7
	31–50	1,703	98.9	0.8	63.2	169.6	74.0	78.4	85.2	95.9	108.8	123.2	134.0
	51–70	1,809	100.7	0.8	57.9	164.0	75.8	80.4	88.7	98.7	111.6	122.8	129.6
	> 70	717	100.2	0.6	64.0	148.1	77.5	82.1	90.5	99.8	109.4	117.4	122.3
	19+	5,282	98.3	0.6	56.4	171.6	73.2	77.0	85.3	96.4	109.1	121.7	129.7
Average sagittal abdominal diameter (cm)*	19–30	526	20.2	0.2	12.2	34.8	14.5	15.3	16.9	19.3	22.8	26.3	28.0
	31–50	867	21.9	0.2	13.1	39.7	15.6	16.6	18.0	21.0	24.8	28.6	30.4
	51–70	854	23.2	0.3	14.4	38.6	16.5	17.4	19.8	23.0	26.1	29.0	31.0
	> 70	325	22.8	0.3	14.3	36.2	16.6	17.6	19.9	22.8	25.3	27.8	28.9
	19+	2,572	22.1	0.2	12.2	39.7	15.5	16.6	18.4	21.6	25.1	28.4	30.0
Waist–hip ratio**	19–30	433	0.86	0.01	0.66	1.08	0.74	0.76	0.80	0.85	0.91	0.96	1.00
	31–50	762	0.88	0.00	0.72	1.09	0.77	0.79	0.82	0.88	0.93	0.97	0.99
	51–70	933	0.91	0.01	0.73	1.11	0.79	0.81	0.86	0.91	0.95	0.98	1.00
	> 70	373	0.93	0.00	0.74	1.17	0.82	0.83	0.89	0.93	0.97	1.00	1.02
	19+	2,501	0.89	0.00	0.66	1.17	0.77	0.80	0.83	0.89	0.94	0.98	1.00

NOTES: cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. Pregnant and lactating women excluded.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018; *2015–2016; **2017–2018.

TABLE L-5 Body Measurement Summary Statistics, Boys 18 Years of Age and Younger, CHMS, 2012–2019

				Percentiles						
Measure	Age (y)	k	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Body mass index (calculated as kg/m^2)	3 y	340	16.2 (0.2)	14.2 (0.2)	14.3 (0.2)	15.1 (0.1)	16.2 (0.1)	17.0 (0.1)	17.7 (0.3)	18.6 (0.4)
	4–8 y	1,717	16.2 (0.1)	13.7 (0.1)	14.2 (0.1)	14.8 (0.1)	15.7 (0.1)	16.8 (0.1)	18.6 (0.4)	21.0 (0.6)
	9–13 y	1,704	19.2 (0.1)	14.7 (0.1)	15.2 (0.1)	16.4 (0.1)	18.3 (0.1)	20.9 (0.3)	24.5 (0.5)	27.1 (0.5)
	14–18 y	1,241	23.7 (0.4)	17.5 (0.2)	18.1 (0.2)	19.5 (0.2)	22.0 (0.2)	26.3 (0.6)	31.0 (1.1)	36.4 (1.6)
Weight (kg)	3 y	345	16.2 (0.2)	13.1 (0.3)	13.9 (0.2)	14.8 (0.1)	16.0 (0.2)	17.5 (0.2)	18.9 (0.3)	19.6 (0.5)
	4–8 y	1,721	23.8 (0.3)	16.0 (0.2)	17.0 (0.2)	19.3 (0.2)	22.4 (0.3)	26.8 (0.5)	31.4 (0.7)	36.6 (1.4)
	9–13 y	1,709	44.2 (0.4)	27.6 (0.3)	29.5 (0.4)	33.8 (0.5)	41.7 (0.4)	51.9 (0.9)	61.5 (1.0)	69.4 (2.2)
	14–18 y	1,242	72.7 (1.5)	49.2 (1.3)	52.9 (0.9)	59.7 (0.6)	68.9 (0.8)	80.6 (1.4)	95.9 (3.0)	114.6 (7.6)
Height (cm)	3 y	340	100.1 (0.4)	93.3 (0.8)	94.2 (0.5)	97.1 (0.5)	100.1 (0.4)	103.2 (0.5)	105.9 (0.6)	107.4 (0.7)
	4–8 y	1,717	120.2 (0.4)	103.0 (0.5)	105.9 (0.5)	111.6 (0.4)	121.0 (0.5)	128.7 (0.5)	134.1 (0.6)	137.3 (0.8)
	9–13 y	1,705	150.4 (0.4)	133.5 (0.7)	136.1 (0.6)	140.8 (0.4)	148.3 (0.6)	159.6 (0.6)	167.7 (0.8)	171.8 (0.8)
	14–18 y	1,242	174.9 (0.4)	161.7 (1.3)	164.8 (0.7)	170.1 (0.4)	174.7 (0.4)	180.5 (0.5)	185.4 (0.5)	187.7 (0.7)
Waist circumference (cm)	3 y	339	49.9 (0.3)	45.1 (0.3)	46.1 (0.3)	47.1 (0.3)	49.8 (0.3)	51.7 (0.4)	54.2 (0.6)	55.8 (1.3)
	4–8 y	1,714	55.2 (0.4)	47.3 (0.3)	48.6 (0.2)	50.9 (0.2)	53.7 (0.3)	57.4 (0.5)	62.3 (0.9)	69.1 (2.2)
	9–13 y	1,710	68.4 (0.4)	55.0 (0.2)	56.6 (0.3)	60.1 (0.4)	66.3 (0.3)	73.2 (0.8)	83.4 (1.2)	93.0 (1.6)
	14–18 y	1,241	82.0 (1.1)	65.5 (0.5)	68.2 (0.5)	72.3 (0.5)	77.5 (0.5)	86.9 (1.3)	101.8 (2.8)	116.0 (3.7)

continued

TABLE L-5 Continued

Measure	Age (y)	k	Percentiles							
			Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Waist–hip ratio	3 y	156	0.91 (0.01)	0.82 (0.02)	0.84 (0.01)	0.88 (0.01)	0.90 (0.01)	0.93 (0.01)	0.97 (0.01)	0.98 (0.01)
	4–8 y	826	0.87 (0.00)	0.79 (0.01)	0.80 (0.00)	0.83 (0.01)	0.87 (0.00)	0.90 (0.00)	0.93 (0.01)	0.96 (0.01)
	9–13 y	869	0.85 (0.00)	0.76 (0.01)	0.78 (0.00)	0.80 (0.00)	0.84 (0.00)	0.88 (0.01)	0.95 (0.01)	0.97 (0.01)
	14–18 y	629	0.84 (0.00)	0.76 (0.01)	0.77 (0.00)	0.80 (0.00)	0.83 (0.01)	0.88 (0.01)	0.93 (0.01)	0.96 (0.01)

NOTES: CHMS = Canadian Health Measures Survey; cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. All results are reported in metric units. All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. BMI status was determined only in those with both valid measured height and weight. Waist–hip ratio was determined only in those with both valid measured waist and hip circumference; hip circumference was not measured in cycles 5 and 6. BMI status in children 18 and under was determined using Centers for Disease Control (CDC) percentiles. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors and are combined between the four cycles according to the documentation from Statistics Canada.

TABLE L-6 Body Measurement Summary Statistics, Girls 18 Years of Age and Younger, CHMS, 2012–2019

				Percentiles						
Measure	Age (y)	k	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Body mass index (calculated as kg/m^2)	3 y	353	16.2 (0.2)	14.1 (0.1)	14.5 (0.1)	15.0 (0.1)	15.8 (0.1)	16.9 (0.2)	18.1 (0.3)	18.7 (1.4)
	4–8 y	1,724	16.3 (0.1)	13.7 (0.1)	14.1 (0.1)	14.8 (0.1)	15.7 (0.1)	17.1 (0.1)	19.1 (0.2)	21.3 (0.4)
	9–13 y	1,705	19.2 (0.2)	14.3 (0.2)	15.1 (0.2)	16.3 (0.1)	18.2 (0.2)	21.0 (0.4)	24.5 (0.5)	27.0 (0.5)
	14–18 y	1,235	22.8 (0.2)	17.2 (0.2)	18.1 (0.2)	19.6 (0.1)	21.6 (0.2)	24.5 (0.3)	29.5 (0.5)	32.3 (0.8)
Weight (kg)	3 y	356	16.0 (0.2)	12.5 (0.3)	13.2 (0.2)	14.6 (0.2)	15.6 (0.2)	16.9 (0.3)	18.9 (0.4)	19.4 (1.2)
	4–8 y	1,726	23.5 (0.2)	15.4 (0.1)	16.4 (0.2)	18.7 (0.2)	22.1 (0.3)	26.4 (0.4)	31.7 (0.7)	37.2 (1.1)
	9–13 y	1,706	43.5 (0.6)	25.8 (0.4)	28.0 (0.4)	33.4 (0.6)	41.7 (0.8)	51.4 (0.9)	61.0 (1.7)	69.4 (1.8)
	14–18 y	1,236	61.0 (0.6)	44.2 (0.9)	47.0 (0.6)	51.9 (0.5)	58.1 (0.4)	67.0 (0.6)	77.6 (2.1)	87.5 (2.6)
Height (cm)	3 y	353	99.4 (0.4)	91.7 (0.4)	92.4 (0.7)	96.3 (0.5)	99.5 (0.5)	102.6 (0.5)	105.3 (0.7)	107.2 (0.7)
	4–8 y	1,726	118.9 (0.4)	102.1 (0.4)	104.7 (0.4)	110.1 (0.4)	118.7 (0.6)	126.9 (0.6)	134.1 (0.6)	137.1 (0.8)
	9–13 y	1,707	149.3 (0.4)	130.1 (0.8)	133.3 (0.6)	141.3 (0.8)	149.5 (0.5)	157.4 (0.6)	164.1 (0.6)	167.4 (0.9)
	14–18 y	1,236	163.6 (0.4)	151.6 (0.8)	154.7 (1.0)	159.1 (0.5)	164.0 (0.4)	167.6 (0.4)	171.6 (0.4)	174.0 (0.6)
Waist circumference (cm)	3 y	349	50.4 (0.4)	44.4 (0.6)	44.9 (0.4)	47.5 (0.4)	49.9 (0.2)	52.6 (0.6)	55.9 (0.7)	57.0 (2.2)
	4–8 y	1,723	55.4 (0.3)	46.5 (0.2)	48.0 (0.3)	50.4 (0.2)	53.9 (0.2)	57.8 (0.4)	64.5 (0.7)	69.9 (1.3)
	9–13 y	1,708	67.5 (0.6)	53.7 (0.4)	55.6 (0.4)	58.9 (0.4)	65.6 (0.6)	73.5 (0.7)	82.5 (1.4)	89.8 (1.4)
	14–18 y	1,234	77.1 (0.6)	63.4 (0.6)	65.1 (0.5)	68.9 (0.4)	74.3 (0.4)	81.8 (0.8)	93.1 (1.5)	100.4 (2.5)

continued

TABLE L-6 Continued

			Percentiles							
Measure	Age (y)	k	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Waist–hip ratio	3 y	158	0.91 (0.01)	0.84 (0.01)	0.85 (0.01)	0.88 (0.00)	0.90 (0.00)	0.94 (0.01)	0.98 (0.01)	1.01 (0.01)
	4–8 y	828	0.88 (0.00)	0.79 (0.01)	0.81 (0.00)	0.84 (0.00)	0.87 (0.00)	0.91 (0.00)	0.96 (0.00)	0.97 (0.01)
	9–13 y	842	0.83 (0.00)	0.74 (0.01)	0.75 (0.00)	0.79 (0.00)	0.82 (0.00)	0.87 (0.01)	0.91 (0.01)	0.94 (0.01)
	14–18 y	624	0.81 (0.00)	0.72 (0.01)	0.74 (0.01)	0.76 (0.00)	0.80 (0.01)	0.85 (0.01)	0.90 (0.01)	0.94 (0.01)

NOTES: CHMS = Canadian Health Measures Survey; cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. All results are reported in metric units. All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. The results from pregnant (adolescents and women) were excluded. Current breastfeeding status was not asked in the questionnaire for CHMS. BMI status was determined only in those with both valid measured height and weight. Waist–hip ratio was determined only in those with both valid measured waist and hip circumference; hip circumference was not measured in cycles 5 and 6. BMI status in children 18 and under were determined using CDC percentiles. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors and are combined between the four cycles according to the documentation from Statistics Canada.

TABLE L-7 Body Measurement Summary Statistics, Men 19 Years of Age and Older, CHMS, 2012–2019

			Percentiles							
Measure	Age (y)	*n*	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Body mass index (calculated as kg/m^2)	19–30	952	26.1 (0.3)	19.6 (0.3)	20.5 (0.2)	22.5 (0.2)	25.0 (0.3)	29.0 (0.5)	32.6 (0.8)	37.5 (1.3)
	31–50	2,826	27.8 (0.3)	20.6 (0.2)	21.9 (0.3)	24.3 (0.2)	26.8 (0.2)	30.6 (0.3)	34.3 (0.6)	38.0 (0.9)
	51–70	2,126	28.4 (0.2)	21.9 (0.3)	23.3 (0.2)	25.0 (0.2)	27.8 (0.2)	30.8 (0.3)	34.1 (0.4)	37.1 (0.6)
	> 70	560	28.2 (0.2)	22.1 (0.5)	23.4 (0.3)	25.5 (0.2)	28.0 (0.3)	30.4 (0.4)	33.3 (0.6)	36.1 (0.8)
	19+	6,464	27.7 (0.1)	20.6 (0.1)	22.0 (0.2)	24.2 (0.1)	26.9 (0.1)	30.4 (0.2)	33.9 (0.3)	37.4 (0.5)
Weight (kg)	19–30	955	83.3 (1.1)	58.7 (1.0)	62.7 (1.0)	70.3 (1.0)	79.7 (1.2)	93.1 (1.5)	106.2 (2.2)	119.8 (4.4)
	31–50	2,828	87.0 (0.9)	62.3 (0.9)	66.6 (1.0)	75.4 (0.7)	84.0 (0.8)	96.9 (1.2)	109.1 (1.7)	117.8 (3.2)
	51–70	2,133	86.8 (0.6)	64.7 (0.7)	68.4 (0.6)	76.0 (0.6)	84.8 (0.8)	96.0 (0.9)	107.1 (1.1)	114.7 (2.0)
	> 70	565	83.3 (0.8)	63.5 (1.5)	66.3 (0.9)	73.4 (1.0)	81.9 (0.9)	91.1 (1.4)	101.5 (1.3)	106.4 (2.7)
	19+	6,481	85.9 (0.5)	62.2 (0.4)	66.6 (0.5)	74.0 (0.5)	83.2 (0.5)	95.7 (0.7)	107.4 (0.8)	116.9 (1.9)
Height (cm)	19–30	952	178.2 (0.5)	166.9 (1.0)	169.8 (0.7)	173.7 (0.5)	178.4 (0.5)	182.8 (0.5)	186.6 (0.6)	188.6 (1.0)
	31–50	2,827	176.6 (0.2)	165.5 (0.5)	167.8 (0.5)	172.5 (0.3)	176.4 (0.3)	180.9 (0.3)	185.4 (0.5)	188.2 (0.4)
	51–70	2,128	174.7 (0.3)	163.1 (0.5)	165.1 (0.5)	169.8 (0.4)	174.5 (0.4)	179.4 (0.4)	183.9 (0.6)	186.9 (0.7)
	> 70	561	171.7 (0.4)	160.1 (0.9)	163.4 (0.8)	167.6 (0.4)	171.5 (0.5)	176.6 (0.5)	179.3 (0.6)	182.4 (0.7)
	19+	6,468	176.0 (0.2)	163.8 (0.3)	166.7 (0.3)	171.4 (0.2)	175.9 (0.3)	180.7 (0.2)	185.1 (0.3)	187.8 (0.4)
Waist circumference (cm)	19–30	955	90.5 (1.0)	73.1 (0.9)	75.3 (0.5)	80.0 (0.6)	86.6 (1.0)	98.8 (1.5)	109.7 (1.9)	117.5 (4.2)
	31–50	2,827	97.2 (0.7)	75.0 (1.1)	80.5 (0.8)	87.7 (0.6)	95.3 (0.5)	104.5 (0.9)	115.8 (1.3)	122.5 (2.1)
	51–70	2,125	101.5 (0.5)	82.9 (0.6)	86.1 (0.5)	92.2 (0.6)	99.9 (0.5)	109.1 (0.5)	117.8 (1.2)	125.7 (1.4)
	> 70	557	103.1 (0.8)	84.6 (1.5)	88.9 (1.0)	94.3 (0.9)	101.4 (1.0)	111.0 (1.0)	118.4 (1.5)	125.1 (1.8)
	19+	6,464	97.6 (0.4)	76.3 (0.5)	80.1 (0.5)	87.3 (0.4)	96.2 (0.4)	105.9 (0.6)	115.8 (0.8)	123.6 (1.4)

continued

TABLE L-7 Continued

Measure	Age (y)	*n*	Percentiles							
			Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Waist–hip ratio	19–30	492	0.88 (0.01)	0.80 (0.01)	0.81 (0.00)	0.84 (0.00)	0.87 (0.01)	0.92 (0.01)	0.99 (0.02)	1.01 (0.01)
	31–50	1,369	0.94 (0.00)	0.82 (0.01)	0.85 (0.01)	0.89 (0.00)	0.94 (0.00)	0.99 (0.01)	1.03 (0.01)	1.05 (0.00)
	51–70	1,100	0.98 (0.00)	0.86 (0.01)	0.89 (0.01)	0.93 (0.00)	0.98 (0.00)	1.02 (0.01)	1.07 (0.01)	1.09 (0.01)
	> 70	262	1.00 (0.01)	0.90 (0.01)	0.92 (0.01)	0.96 (0.01)	1.00 (0.01)	1.04 (0.01)	1.08 (0.01)	1.10 (0.01)
	19+	3,223	0.95 (0.00)	0.82 (0.00)	0.84 (0.00)	0.89 (0.00)	0.95 (0.00)	1.00 (0.00)	1.04 (0.00)	1.07 (0.00)

NOTES: CHMS = Canadian Health Measures Survey; cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. All results are reported in metric units. All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. BMI status was determined only in those with both valid measured height and weight. Waist–hip ratio was determined only in those with both valid measured waist and hip circumference; hip circumference was not measured in cycles 5 and 6. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors and are combined between the four cycles according to the documentation from Statistics Canada.

TABLE L-8 Body Measurement Summary Statistics, Women 19 Years of Age and Older, CHMS, 2012–2019

				Percentiles						
Measure	Age (y)	*n*	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Body mass index (calculated as kg/m^2)	19–30	948	25.6 (0.4)	18.2 (0.5)	19.4 (0.3)	21.5 (0.3)	23.8 (0.4)	28.2 (0.7)	34.6 (1.1)	38.7 (1.0)
	31–50	2,768	27.1 (0.3)	18.9 (0.3)	20.2 (0.3)	22.2 (0.2)	25.4 (0.3)	30.1 (0.5)	36.8 (0.7)	41.1 (1.3)
	51–70	2,058	28.0 (0.3)	19.8 (0.2)	21.0 (0.2)	23.4 (0.2)	27.0 (0.3)	31.5 (0.4)	36.7 (0.5)	40.0 (0.8)
	> 70	671	27.7 (0.3)	20.1 (0.5)	21.8 (0.5)	24.3 (0.3)	27.0 (0.3)	30.1 (0.4)	33.9 (0.6)	36.5 (0.7)
	19+	6,445	27.1 (0.2)	19.3 (0.2)	20.3 (0.2)	22.4 (0.2)	25.8 (0.3)	30.4 (0.4)	36.1 (0.5)	40.0 (0.6)
Weight (kg)	19–30	949	69.0 (1.2)	45.4 (1.3)	50.6 (1.4)	57.7 (0.9)	65.0 (1.2)	75.0 (1.6)	94.7 (3.7)	111.9 (3.4)
	31–50	2,771	72.6 (0.9)	50.1 (0.7)	53.7 (0.6)	58.8 (0.8)	68.2 (0.6)	81.7 (1.2)	98.7 (2.7)	113.7 (3.0)
	51–70	2,064	72.3 (0.7)	49.8 (0.8)	53.7 (0.6)	59.9 (0.6)	69.0 (0.7)	81.6 (1.1)	95.0 (1.2)	103.4 (2.0)
	> 70	676	69.3 (0.8)	48.7 (1.2)	53.8 (1.3)	60.3 (0.8)	68.3 (0.7)	75.8 (1.1)	85.6 (1.6)	93.4 (1.7)
	19+	6,460	71.6 (0.7)	48.9 (0.6)	53.1 (0.5)	58.8 (0.5)	68.1 (0.6)	80.1 (0.9)	95.5 (1.3)	110.0 (2.1)
Height (cm)	19–30	948	164.0 (0.5)	151.6 (1.6)	155.7 (1.0)	158.9 (0.6)	163.4 (0.5)	169.0 (0.7)	173.1 (0.6)	175.0 (1.6)
	31–50	2,768	163.7 (0.3)	153.3 (0.6)	155.5 (0.3)	159.0 (0.4)	163.2 (0.3)	168.1 (0.4)	172.2 (0.5)	175.1 (0.5)
	51–70	2,065	160.6 (0.3)	149.7 (0.7)	152.4 (0.4)	156.3 (0.3)	160.4 (0.4)	165.1 (0.4)	169.2 (0.4)	171.5 (0.4)
	> 70	671	158.1 (0.3)	148.0 (0.7)	150.3 (0.7)	154.2 (0.5)	157.8 (0.4)	162.1 (0.4)	166.1 (0.4)	168.4 (0.5)
	19+	6,452	162.3 (0.2)	150.9 (0.3)	153.7 (0.3)	157.5 (0.2)	162.1 (0.3)	166.9 (0.3)	171.3 (0.3)	174.1 (0.4)
Waist circumference (cm)	19–30	944	84.6 (1.0)	65.8 (1.3)	69.3 (1.1)	73.9 (0.6)	79.7 (1.3)	91.3 (1.6)	106.9 (2.9)	116.9 (3.0)
	31–50	2,765	90.1 (0.9)	69.8 (0.5)	72.9 (0.4)	78.2 (0.7)	86.4 (0.8)	98.1 (1.2)	112.1 (2.0)	123.2 (2.9)
	51–70	2,067	94.1 (0.6)	72.9 (0.7)	76.0 (0.5)	82.4 (0.7)	92.4 (0.7)	103.6 (0.9)	113.9 (1.0)	121.4 (1.2)
	> 70	672	94.2 (0.7)	74.1 (1.1)	78.0 (1.4)	85.7 (1.1)	93.2 (0.7)	101.1 (0.8)	111.0 (1.3)	117.0 (1.1)
	19+	6,448	90.7 (0.6)	69.9 (0.5)	73.1 (0.3)	78.4 (0.6)	87.9 (0.7)	100.0 (0.9)	112.4 (0.9)	121.1 (1.3)

continued

TABLE L-8 Continued

			Percentiles							
Measure	Age (y)	*n*	Mean (SE)	5th (SE)	10th (SE)	25th (SE)	50th (SE)	75th (SE)	90th (SE)	95th (SE)
Waist–hip ratio	19–30	516	0.83 (0.01)	0.74 (0.02)	0.74 (0.01)	0.78 (0.01)	0.82 (0.01)	0.88 (0.01)	0.93 (0.01)	0.97 (0.01)
	31–50	1,352	0.87 (0.00)	0.76 (0.01)	0.78 (0.01)	0.82 (0.00)	0.87 (0.01)	0.91 (0.00)	0.95 (0.01)	0.98 (0.01)
	51–70	1,034	0.89 (0.00)	0.77 (0.00)	0.80 (0.00)	0.84 (0.00)	0.88 (0.00)	0.93 (0.00)	0.97 (0.00)	0.99 (0.01)
	> 70	345	0.89 (0.00)	0.78 (0.01)	0.81 (0.01)	0.85 (0.01)	0.89 (0.00)	0.94 (0.00)	0.97 (0.01)	1.00 (0.01)
	19+	3,247	0.87 (0.00)	0.75 (0.00)	0.78 (0.00)	0.82 (0.00)	0.87 (0.00)	0.92 (0.00)	0.96 (0.00)	0.99 (0.00)

NOTES: CHMS = Canadian Health Measures Survey; cm = centimeter; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. All results are reported in metric units. All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. The results from pregnant (adolescents and women) were excluded. Current breastfeeding status was not asked in the questionnaire for CHMS. BMI status was determined only in those with both valid measured height and weight. Waist–hip ratio was determined only in those with both valid measured waist and hip circumference; hip circumference was not measured in cycles 5 and 6. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors, and are combined between the four cycles according to the documentation from Statistics Canada.

TABLE L-9 Population Prevalence of Weight Categories, Children, NHANES, 2015–2018

Age	Sex	Underweight	SE	Normal	SE	Overweight	SE	Obesity	SE
2–3 y	M	3.0	1.0	68.6	3.5	14.9	2.6	13.5	2.3
	F	*		76.2	2.5	13.8	2.1	6.9	0.9
4–8 y	M	3.5	1.0	64.2	2.2	15.2	1.2	17.1	1.7
	F	3.2	0.8	64.2	2.0	14.5	1.2	18.2	1.7
9–13 y	M	3.3	1.1	58.2	1.9	15.1	1.3	23.4	1.8
	F	2.5	0.6	59.9	1.9	18.9	1.7	18.7	1.6
14–18 y	M	6.3	1.8	57.0	2.4	15.8	1.3	20.8	1.9
	F	2.5	0.8	57.4	2.4	20.6	1.6	19.5	1.6

NOTES: F = female; M = male; SE = standard error; y = year. Pregnant and lactating adolescents excluded. Underweight: < 5th percentile of body mass index (BMI) for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obesity: 95th percentile and above (CDC).

*Estimate does not meet National Center for Health Statistics standards of reliability; see Series Report 2, Number 175 ([https://www.cdc.gov/nchs/data/series/sr_02/sr02_175.pdf).

SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

TABLE L-10a Population Prevalence of Weight Categories, Children, CHMS, 2012–2019

Age	Sex	Underweight (SE)	Normal (SE)	Overweight (SE)	Obese (SE)
3 y	M	4.8* (1.7)	72.7 (3.8)	14.7* (3.3)	7.8* (2.9)
	F	3.3* (1.0)	72.3 (3.9)	16.8* (3.4)	7.6* (2.3)
4–8 y	M	6.3* (1.1)	74.1 (1.9)	10.5 (1.1)	9.1 (1.3)
	F	3.5 (0.5)	74.5 (1.6)	12.9 (1.5)	9.0 (0.9)
9–13 y	M	4.0* (0.8)	69.1 (2.1)	15.9 (1.4)	11.0 (1.3)
	F	4.7* (0.9)	71.3 (2.0)	15.1 (1.8)	8.9 (1.1)
14–18 y	M	5.0*(0.9)	62.9(2.6)	13.7(1.7)	18.4(2.4)
	F	3.6*(1.2)	73.2(1.7)	13.2(1.5)	10.0(1.1)

NOTES: CHMS = Canadian Health Measures Survey; F = female; M = male; SE = standard error; y = year. All results are reported in metric units. Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obese: 95th percentile and above (CDC). All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. The results from pregnant (adolescents and women) were excluded. Current breastfeeding status was not asked in the questionnaire for CHMS. BMI status was determined only in those with both valid measured height and weight. Waist–hip ratio was determined only in those with both valid measured waist and hip circumference; hip circumference was not measured in cycles 5 and 6. BMI status in children 18 and under were determined using CDC percentiles. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors and are combined between the four cycles according to the documentation from Statistics Canada.

*Data with a coefficient of variation from 16.6% or higher; interpret with caution.

TABLE L-10b Population Prevalence of Weight Categories, Children, WHO Criteria, CHMS, 2012–2019

Age	Sex	Thinness (SE)	Normal (SE)	At Risk of Overweight (SE)	Overweight (SE)	Obese (SE)
3 y	M		70.7 (4.5)	22.2 (3.3)	**	< 3***
	F		73.3 (4.2)	19.8* (3.6)	**	**
4–5 y	M		72.4 (3.7)	19.3* (3.4)	4.3* (1.2)	**
	F		78.9 (3.3)	17.0* (3.2)	< 3***	**
5–8 y	M	F	75.5 (2.6)		12.6 (1.4)	9.1 (1.4)
	F	< 3***	74.3 (1.9)		16.6 (1.7)	8.4 (1.0)
9–13 y	M	2.2* (0.7)	64.0 (2.0)		20.5 (1.4)	13.4 (1.2)
	F	2.4* (0.5)	67.7 (2.4)		20.2 (2.1)	9.7 (1.1)
14–18 y	M	2.4* (0.6)	61.9 (2.4)		18.0 (1.8)	17.6 (2.4)
	F	**	70.3 (1.9)		17.3 (1.8)	10.8 (1.1)

NOTES: CHMS = Canadian Health Measures Survey; F = female; M = male; SD = standard deviation; SE = standard error; WHO = World Health Organization; y = year. Excludes pregnant adolescents. WHO criteria 61 months to 227 months. ≤ 2 SD below the mean = thinness; > 22SD below the mean and ≤ 1 SD above the mean = normal; greater than 1SD and ≤ 2 SD above the mean = overweight; > 2 SD above the mean = obesity.

*Data with a coefficient of variation from 16.6% or higher; interpret with caution.

**Data with a coefficient of variation greater than 33.3% with a 95% confidence interval not entirely between 0 and 3%; suppressed due to extreme sampling variability.

***Data with a coefficient of variation greater than 33.3% with a 95% confidence interval entirely between 0 and 3%; interpret with caution.

TABLE L-11 Population Prevalence of Weight Categories and Abdominal Obesity, Adults, NHANES, 2015–2018

Age	Sex	Under weight	SE	Normal	SE	Over weight	SE	All Obesity
19–30 y	M	3.3	0.7	37.3	2.2	26.9	2.3	32.5
	F	3.8	0.8	38.8	2.6	23.4	1.9	34.1
31–50 y	M	0.51	0.11	18.1	1.4	37.6	2.0	43.7
	F	1.1	0.3	28.4	2.0	27.1	1.6	43.4
51–70 y	M	0.77	0.28	19.7	1.9	36.9	2.0	42.6
	F	1.6	0.5	24.8	1.6	28.2	1.8	45.4
> 70 y	M	0.88	0.38	21.0	1.7	41.4	2.0	36.7
	F	0.77	0.31	25.8	1.8	34.3	1.7	39.1
19+ y	M	1.2	0.2	23.2	1.1	35.4	1.2	40.2
19+ y	F	1.8	0.2	28.8	1.2	27.8	0.7	41.7

NOTES: F = female; M = male; SE = standard error; y = year. Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0; obesity class I: BMI 30 to < 35; obesity class II: BMI 35 to < 40; obesity class III: BMI ≥ 40 (CDC). Waist circumference > 102 cm for men and > 88 cm for women. Pregnant and lactating women excluded.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

SE	Obesity Class I	SE	Obesity Class II	SE	Obesity Class III	SE	Abdominal Obesity	SE
3.1	19.8	2.2	7.8	1.2	4.9	0.8	30.6	2.9
2.3	15.1	1.3	9.9	1.7	9.1	1.1	50.9	2.3
2.2	24.6	1.6	11.0	1.1	8.1	0.9	48.3	2.2
1.6	19.2	1.0	10.9	0.9	13.3	1.4	67.9	1.7
2.3	26.1	2.4	10.6	1.3	5.9	0.8	57.3	2.3
2.1	21.9	1.6	13.2	1.1	10.2	1.1	76.3	2.1
2.7	25.6	2.1	8.6	1.8	2.5	0.8	62.7	2.7
1.8	23.6	2.4	10.3	1.5	5.2	1.0	80.1	1.9
1.8	24.2	1.4	9.9	0.6	6.1	0.6	48.7	1.7
1.4	19.9	0.8	11.4	0.7	10.3	0.7	69.1	1.4

TABLE L-12 Population Prevalence of Weight Categories and Abdominal Obesity, Adults, CHMS, 2012–2019

Age	Sex	Underweight (SE)	Normal (SE)	Overweight (SE)
19–30 y	M	2.2* (0.8)	47.6 (2.7)	31.1 (2.1)
	F	5.4* (1.5)	52.6 (3.1)	23.3 (2.4)
31–50 y	M	0.8* (0.3)	30.0 (1.9)	40.0 (1.9)
	F	3.1* (0.8)	42.7 (2.2)	29.1 (1.8)
51–70 y	M	0.2* (0.1)	24.4 (1.5)	45.2 (1.8)
	F	1.5* (0.6)	35.4 (1.9)	32.4 (1.6)
> 70 y	M	**	20.2 (2.5)	50.9 (3.3)
	F	1.3* (0.4)	28.0 (3.0)	44.6 (3.3)
19+ y	M	0.9* (0.2)	31.1 (1.0)	40.6 (1.2)
19+ y	F	2.9* (0.5)	41.1 (1.6)	30.2 (1.1)

NOTES: CHMS = Canadian Health Measures Survey; F = female; M = male; SE = standard error; y = year. All results are reported in metric units. Underweight: BMI < 18.5; normal weight: BMI 18.5 to <25; overweight: BMI 25.0 to <30; obesity: BMI ≥ 30.0; obesity class I: BMI 30 to < 35; obesity class II: BMI 35 to < 40; obesity class III: BMI ≥ 40 (CDC). Waist circumference >102 cm for men and > 88 cm for women. All body measurement results are based on CHMS cycles 3 (2012–2013), 4 (2014–2015), 5 (2016–2017), and 6 (2018–2019). The population for all cycles was 3 to 79 years of age. The results from pregnant (adolescents and women) were excluded. Current breastfeeding status was not asked in the questionnaire for CHMS. BMI status was determined only in those with both valid measured height and weight. All results use survey weights to obtain estimates for the Canadian population and bootstrap weights to obtain standard errors and are combined between the four cycles according to the documentation from Statistics Canada.

*Data with a coefficient of variation (CV) 16.6% or higher; interpret with caution.

**Results are not reported in cells with responses from fewer than 5 unweighted respondents. Percentiles with fewer than 5 observations on either side of the percentile are also not reported.

All Obesity (SE)	Obesity Class I (SE)	Obesity Class II (SE)	Obesity Class III (SE)	Abdominal Obesity (SE)
19.0 (2.0)	12.3* (2.2)	3.4* (1.1)	3.4* (1.0)	18.8 (2.5)
18.7 (2.3)	9.5* (1.7)	5.0* (1.3)	4.2* (1.1)	31.4 (2.9)
29.3 (2.2)	20.0 (1.6)	6.3 (0.9)	3.0* (0.9)	31.3 (2.2)
25.1 (1.9)	12.1 (1.3)	7.2 (1.1)	5.8* (1.1)	46.2 (2.4)
30.2 (1.8)	22.1 (1.6)	5.7E (1.0)	2.4* (0.5)	44.0 (1.9)
30.7 (1.8)	16.7 (1.2)	9.1 (1.4)	4.8 (0.7)	60.4 (1.8)
28.4 (2.8)	21.8 (2.7)	4.9 (0.8)	1.7* (0.6)	47.8 (3.1)
26.0 (2.6)	18.7 (2.3)	5.1* (1.1)	2.2* (0.6)	68.5 (2.9)
27.4 (1.3)	19.2 (1.1)	5.4 (0.6)	2.8* (0.5)	34.1 (1.4)
25.9 (1.4)	13.7 (0.8)	7.3 (0.8)	4.9 (0.5)	49.9 (1.7)

TABLE L-13 Body Composition Summary Statistics, Boys and Men, 8–59 years, NHANES, 2015–2018

Measure	Age	*N*	Mean	SE
Total body fat mass (kg)	8 y	176	9.5	0.4
	9–13 y	751	14.4	0.4
	14–18 y	637	17.6	0.6
	19–30 y	806	22.5	0.5
	31–50 y	1,191	25.9	0.4
	51–59 y	554	25.2	0.6
	19–59 y	2,551	24.7	0.3
Percent body fat (%)	8 y	176	28.1	0.6
	9–13 y	751	29.0	0.4
	14–18 y	637	23.5	0.5
	19–30 y	806	25.5	0.3
	31–50 y	1,191	27.8	0.2
	51–59 y	554	27.9	0.4
	19–59 y	2,551	27.1	0.2
Lean mass index	8 y	175	12.8	0.1
	9–13 y	749	14.4	0.1
	14–18 y	636	17.8	0.2
	19–30 y	803	20.1	0.2
	31–50 y	1,186	21.1	0.1
	51–59 y	553	20.8	0.2
	19–59 y	2,542	20.8	0.1
Fat mass index	19–30 y	803	7.4	0.2
	31–50 y	1,186	8.5	0.1
	51–59 y	553	8.3	0.2
	19–59 y	2,542	8.1	0.1
Visceral adipose tissue mass (g)	8 y	184	192.8	6.0
	9–13 y	777	235.3	5.1
	14–18 y	697	247.9	5.4
	19–30 y	904	358.7	9.7
	31–50 y	1,405	570.7	10.6
	51–59 y	659	733.1	17.0
	19–59 y	2,968	540.6	9.4

NOTES: g = gram; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. Includes dual-energy x-ray absorptiometry (DXA) data. Fat mass index calculated as fat mass/height^2 and lean mass index as lean mass (including bone mineral content)/height^2.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

Percentiles						
5th	10th	25th	50th	75th	90th	95th
4.5	4.9	5.7	7.7	12.4	16.7	20.2
5.9	6.6	8.1	11.3	18.1	26.7	32.2
8.0	8.5	10.3	13.4	21.0	32.8	41.1
9.1	10.4	13.7	20.1	28.4	36.7	45.7
12.4	15.1	19.4	24.4	30.7	39.5	45.5
11.5	14.9	19.1	24.4	29.3	36.6	44.4
10.6	12.6	17.6	23.5	29.9	38.5	45.6
18.8	19.5	22.7	26.6	32.1	39.2	40.7
17.7	18.9	21.9	27.5	35.8	40.5	42.5
14.6	15.5	17.3	21.1	28.5	34.7	38.9
14.8	15.9	19.8	25.0	31.0	35.4	37.0
18.0	20.7	24.3	27.6	31.3	34.9	37.4
17.5	21.2	24.5	28.1	31.2	34.1	36.5
15.9	18.6	22.9	27.1	31.2	35.0	37.1
10.8	11.0	11.7	12.6	13.7	14.7	15.2
11.5	11.7	12.7	14.0	15.7	17.3	18.5
13.5	14.5	16.0	17.4	19.3	21.5	23.2
15.4	16.2	17.9	19.8	22.0	23.9	25.4
16.9	17.6	19.0	20.8	22.9	24.7	26.6
16.9	17.4	18.7	20.4	22.6	24.5	26.0
16.2	17.1	18.6	20.5	22.6	24.4	26.1
2.9	3.4	4.5	6.5	9.5	12.1	14.7
4.1	4.8	6.4	8.0	10.0	12.5	14.7
3.8	4.7	6.4	7.9	9.5	11.9	13.9
3.5	4.1	5.8	7.6	9.8	12.3	14.6
125.6	132.3	142.0	174.0	217.8	287.4	317.3
132.4	143.7	164.4	197.0	280.5	374.2	448.3
149.1	161.6	178.4	209.7	274.4	390.1	472.2
175.0	187.6	220.8	289.2	446.4	632.3	761.8
226.5	265.0	375.0	540.9	724.5	897.5	1043.7
287.7	363.0	500.3	696.8	939.1	1104.0	1290.7
193.9	220.9	306.8	486.8	712.5	933.6	1072.8

TABLE L-14 Body Composition Summary Statistics, Girls and Women, 8–59 years, NHANES, 2015–2018

Measure	Age	*N*	Mean	SE
Total body fat mass (kg)	8 y	139	10.9	0.5
	9–13 y	703	15.6	0.4
	14–18 y	598	23.2	0.5
	19–30 y	749	28.0	0.9
	31–50 y	1,278	31.8	0.5
	51–59 y	610	31.8	0.7
	19–59 y	2,637	30.7	0.5
Percent body fat (%)	8 y	139	32.8	0.7
	9–13 y	703	32.4	0.3
	14–18 y	598	34.7	0.4
	19–30 y	749	36.7	0.5
	31–50 y	1,278	38.9	0.3
	51–59 y	610	40.3	0.3
	19–59 y	2,637	38.6	0.3
Lean mass index	8 y	139	12.3	0.2
	9–13 y	700	13.7	0.1
	14–18 y	598	15.8	0.1
	19–30 y	748	17.2	0.2
	31–50 y	1,276	18.0	0.1
	51–59 y	608	17.4	0.2
	19–59 y	2,632	17.6	0.1
Fat mass index	19–30 y	748	10.6	0.3
	31–50 y	1,276	12.1	0.2
	51–59 y	608	12.2	0.3
	19–59 y	2,632	11.7	0.2
Visceral adipose tissue mass (g)	8 y	155	133.6	10.7
	9–13 y	778	169.4	5.8
	14–18 y	631	218.2	8.6
	19–30 y	807	322.4	12.2
	31–50 y	1,392	488.0	13.1
	51–59 y	686	596.8	18.8
	19–59 y	2,885	470.1	11.0

NOTES: g = gram; kg = kilogram; m = meter; mo = month; SE = standard error; y = year. Includes dual-energy x-ray absorptiometry (DXA) data. Fat mass index calculated as fat mass/height^2 and lean mass index as lean mass (including bone mineral content)/height^2. Excludes pregnant and lactating adolescents and women.
SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

Percentiles						
5th	10th	25th	50th	75th	90th	95th
4.9	5.7	7.3	9.2	13.8	17.9	19.7
6.9	7.9	9.5	13.5	20.1	26.3	31.9
11.7	13.1	16.5	20.9	28.1	37.3	43.2
12.8	14.5	18.2	25.9	35.4	45.0	51.5
15.1	17.4	22.7	29.7	39.0	49.8	56.3
15.1	18.6	23.9	30.4	37.5	46.0	55.2
14.3	16.2	21.2	29.0	37.6	47.6	55.4
21.9	23.6	27.8	31.7	37.9	41.5	43.4
21.9	24.1	27.3	31.9	37.4	41.7	43.9
24.2	26.4	29.8	34.1	39.8	43.4	45.8
24.4	26.5	31.0	37.5	41.8	45.8	47.4
26.9	29.6	35.1	39.6	43.4	46.5	48.3
29.5	32.1	36.8	41.3	44.3	46.9	48.4
26.2	29.0	34.5	39.5	43.3	46.4	48.2
10.1	10.4	11.0	12.1	13.2	14.2	15.5
11.0	11.3	12.0	13.3	15.1	16.9	17.6
12.6	13.0	14.0	15.4	17.1	18.8	20.1
13.1	13.8	15.0	16.6	19.0	21.4	22.8
13.9	14.4	15.6	17.3	19.8	22.4	23.8
13.3	13.7	15.1	16.9	19.0	21.5	23.2
13.5	14.1	15.3	17.0	19.3	21.9	23.3
4.8	5.4	6.7	9.9	13.5	17.2	19.0
5.7	6.5	8.4	11.3	14.6	18.8	20.8
6.0	7.0	9.1	11.7	14.8	17.5	20.6
5.4	6.1	8.1	11.0	14.3	18.1	20.5
33.4	46.2	65.8	85.8	158.0	283.5	359.2
36.6	60.5	87.6	129.2	230.1	333.1	418.1
68.2	85.9	118.0	177.5	281.2	402.5	494.0
87.7	101.6	151.5	267.6	427.7	588.8	727.6
138.9	173.7	275.1	431.9	635.1	884.8	1029.8
151.5	212.8	367.7	577.5	786.9	966.5	1131.9
110.2	142.8	244.5	413.3	631.3	856.0	1019.0

TABLE L-15 Population Prevalence of Intentional Weight Loss by Weight Category, Children, NHANES, 2015–2018

Trying to Lose Weight Currently or in the Past Year (%)					
Age	Sex	Overall	SE	Underweight	SE
8 y	M	[a]		[a]	
	F	[a]		[a]	
9–13 y	M	53.1	2.6	[a]	
	F	53.7	2.3	[a]	
14–18 y	M	33.3	2.2	[b]	
	F	47	2.2	[a]	

NOTES: F = female; M = male; SE = standard error; y = year. Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obesity: 95th percentile and above (CDC). Excludes pregnant and lactating adolescents.

[a] Sample size < 30.

[b] Does not meet NCHS presentation standards.

SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

TABLE L-16 Population Prevalence of Intentional Weight Loss by Weight Category, Adults, NHANES, 2015–2018

Trying to Lose Weight Currently or in the Past Year (%)							
Age	Sex	Overall	SE	Underweight	SE	Normal Weight	SE
19–30 y	M	27.2	2.1	[b]		7.4	1.8
	F	42.3	1.3	[b]		29	2.3
31–50 y	M	34.7	2.3	[a]		13	3.3
	F	42.9	1.6	[a]		27.4	3.4
51–70 y	M	31.5	2.1	[a]		[b]	
	F	45.4	1.9	[a]		31.3	4.2
> 70 y	M	25.8	2	[a]		2.5	1
	F	29.4	2.4	[a]		[b]	
19+ y	M	31	1.1	[b]		9.5	1.5
19+ y	F	41.6	1	[b]		26.6	1.6

NOTE: F = female; M = male; SE = standard error; y = year. Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0; obesity class I: BMI 30 to < 35; obesity class II: BMI 35 to < 40; obesity class III: BMI ≥ 40 (CDC).

[a] Sample size < 30.

[b] Does not meet NCHS presentation standards.

SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

Normal	SE	Overweight	SE	Obesity	SE
[a]		[a]		[a]	
[a]		[a]		[a]	
38.9	3.4	72.8	3.7	82.2	3.2
37	3.2	73.8	5.2	91.7	2.2
16.8	1.9	55.3	6.5	69.7	4.1
33.7	2.5	59.9	4.7	78.3	3.2

Overweight	SE	All Obesity	SE	Obesity Class I	SE	Obesity Class II	SE	Obesity Class III	SE
34.6	3.8	46.5	4	42.8	4	[b]		[b]	
48.5	4.4	57.9	2.9	59.5	3.9	53.6	5.1	60.2	5.9
37.1	2.8	41.9	3.3	33.9	3.6	47.3	5.2	59.2	6
48.7	3.4	50.6	2	43.1	3.3	52.8	3.7	59.7	3.2
27.4	3.4	44.8	3.1	42.9	3.6	[b]		56.2	5.1
50.6	3.2	51.6	3.1	49.3	3.3	53.9	5.3	53.5	6.4
22.3	2.6	43.6	3.7	41.9	4.3	[b]		[a]	
35.1	3.3	38.1	3.8	33.6	5.7	[b]		[b]	
31.5	1.5	43.9	1.9	39.6	2.3	46.2	4.6	57.4	3.6
46.8	2	50.4	1.7	46.1	1.9	52.7	2.8	56.1	2.6

TABLE L-17 Population Prevalence of Intentional Weight Loss of 10 Pounds or More, Adults, NHANES, 2015–2018

Age	Sex	Times Lost Weight	Overall	SE	Under-weight	SE	Normal Weight	SE
19–30 y	M	0	52.9	2.4	[b]		79.6	2.4
		1 to 2	28.5	2.1	[b]		15.5	2.3
		3 to 5	12.9	2	[b]		3	0.8
		6 to 10	2.5	0.6	[b]		0.5	0.4
		11+	3.2	0.7	[b]		1.3	0.8
	F	0	45.7	2.1	[b]		66	2.6
		1 to 2	35.6	2	[b]		28	2.6
		3 to 5	13.3	1.5	[b]		5.9	1.5
		6 to 10	3.8	0.9	[b]		0.1	0.1
		11+	1.6	0.6	[b]		[b]	
31–50 y	M	0	43.4	1.9	[a]		77.1	3
		1 to 2	27.6	1.8	[a]		16.6	2.7
		3 to 5	16.7	1.7	[a]		[b]	
		6 to 10	5.5	1	[a]		0.8	0.4
		11+	6.8	0.8	[a]		1.5	1
	F	0	29.5	1.9	[a]		48.9	4
		1 to 2	33.3	1.8	[a]		27.3	3
		3 to 5	23.6	1.4	[a]		21.1	3.1
		6 to 10	7.8	0.7	[a]		1.7	0.7
		11+	5.9	1	[a]		1.1	0.9
51–70 y	M	0	44.1	1.9	[a]		79.8	3.9
		1 to 2	24.3	1.8	[a]		9.7	2.3
		3 to 5	17.7	1.7	[a]		[b]	
		6 to 10	5.9	1.2	[a]		[b]	
		11+	8	1.2	[a]		[b]	
	F	0	29.6	1.8	[a]		50.2	3.7
		1 to 2	29	1.6	[a]		28.6	3.4
		3 to 5	20.9	1.5	[a]		15.1	3
		6 to 10	10.1	1	[a]		1.7	0.8
		11+	10.4	1.2	[a]		[b]	

Over-weight	SE	All Obesity	SE	Obesity Class I	SE	Obesity Class II	SE	Obesity Class III	SE
45.8	5.4	23.2	2.9	28.1	4.2	15.6	3.3	[b]	
38	5.5	38.4	3.8	38.5	4.4	32.9	6.1	[b]	
[b]		25.9	3.7	24.5	4.4	33	6.3	[b]	
1.5	0.9	[b]		[b]		[b]		[b]	
2.1	0.8	6.7	1.5	[b]		[b]		[b]	
38.4	4.9	21.1	2.4	24	3.7	16.5	3.5	21.4	21.4
37.7	4.5	47	3.4	53.8	4	58.6	5.3	22.3	4.8
15.3	3.2	22.1	2.5	15.6	3.2	[b]		41.5	6.7
[b]		8	1.9	[b]		[b]		[b]	
[b]		1.8	0.7	[b]		[b]		[b]	
52.3	3.5	21.1	2	28.1	3.1	14.8	3.1	[b]	
25.3	2.4	34.5	2.6	38.2	3.1	34	5.3	23.9	4.7
14.1	2.1	24.5	3	20.3	2.9	27.1	5.7	33.4	5.8
3.3	1	9.4	2	5.3	1.3	[b]		[b]	
5	1.4	10.6	1.5	8.1	2	14	3.5	13.2	3.2
27	3.4	16.5	1.7	16.5	1.7	17.9	3.1	9	1.9
37.6	2.7	35.1	2.6	40	4.4	31.9	4.2	30.5	3.8
23.9	3	25.7	2	20.1	1.8	29.9	4.9	30.4	4
6.8	1.8	12.7	1.2	12.9	2.5	13.2	3.8	12	1.8
[b]		10	1.6	[b]		[b]		18.1	3.7
48.7	2.4	22.7	2.3	27.7	2.6	[b]		[b]	
25.6	3.3	30.4	2.1	33.9	2.6	23.6	4	[b]	
14.1	2.5	26.4	2.7	21.6	3.2	35.2	6.3	[b]	
6.8	1.7	7.1	1.8	[b]		[b]		10.6	2.8
4.8	1.4	13.5	2.2	[b]		20.6	5.8	20.4	5.3
29	3	17.3	1.9	23.2	3.3	11.2	2	[b]	
38.4	3.8	24.1	1.9	26.9	2.8	23.6	3.6	18.6	3.9
18.5	3.1	25.5	2	23.7	2.5	27.6	4.8	26.6	4.3
9.5	2.2	15.4	1.8	8	2.1	23.4	4.5	21.2	5.5
[b]		17.7	2.1	18.2	3.6	14.3	3.6	21.1	5.4

continued

TABLE L-17 Continued

Age	Sex	Times Lost Weight	Overall	SE	Under-weight	SE	Normal Weight	SE
> 70 y	M	0	52.5	2	[a]		78	3.4
		1 to 2	24.7	1.8	[a]		16.9	2.3
		3 to 5	13.7	1.6	[a]		[b]	
		6 to 10	5.9	1.5	[a]		[b]	
		11+	3.2	0.6	[a]		[b]	
	F	0	41.6	2.1	[a]		65.8	4.1
		1 to 2	25.1	2	[a]		25.7	4
		3 to 5	15.4	1.7	[a]		[b]	
		6 to 10	8.9	1.3	[a]		[b]	
		11+	8.9	1.4	[a]		[b]	
19+ y	M	0	46.8	1.3	99.2	0.8	78.8	1.7
		1 to 2	26.4	1	[b]		14.4	1.5
		3 to 5	15.8	0.9	[b]		4.1	0.8
		6 to 10	5	0.7	[b]		1	0.5
		11+	6	0.5	[b]		1.7	0.4
	F	0	34.5	1.3	[b]		55.9	1.9
		1 to 2	31.2	1.2	[b]		27.6	1.8
		3 to 5	19.5	0.8	[b]		13.1	1.4
		6 to 10	7.9	0.5	[b]		1.4	0.4
		11+	7	0.5	[b]		2	0.7

NOTE: F = female; M = male; SE = standard error; y = year. Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0; obesity class I: BMI 30 to < 35; obesity class II: BMI 35 to < 40; obesity class III: BMI ≥ 40 (CDC).

[a] Sample size < 30.

[b] Does not meet presentation standards.

SOURCE: National Health and Nutrition Examination Survey (NHANES), 2015–2018.

Over-weight	SE	All Obesity	SE	Obesity Class I	SE	Obesity Class II	SE	Obesity Class III	SE
55.5	2.8	33.4	3	32.6	3.7	[b]		[a]	
28.3	3.2	25.5	2.7	28.7	3.1	[b]		[a]	
12.6	2.4	21.8	3.7	21.5	4.5	[b]		[a]	
[b]		12.9	3.2	[b]		[b]		[a]	
1.3	0.4	6.3	1.5	7.1	1.8	[b]		[a]	
42.3	3.2	25	3.4	28.5	5	23.6	6.5	[b]	
26.3	3.2	23.9	3.2	20.9	3.8	29.4	5.7	[b]	
13.8	2.7	24.7	3	24	4	28	6.6	[b]	
8.5	2.1	13.4	2.2	13.5	2.7	[b]		[b]	
9	2.4	12.9	2.6	13.1	3.5	[b]		[b]	
50.5	2.1	23.3	1.4	28.5	1.9	17.8	2.6	11.6	2.4
27.9	1.8	32.9	1.4	35.6	1.6	28.8	2.4	28.6	3.6
13.6	1.4	25.1	1.7	21.7	1.8	30.7	3	29.5	4
4	0.8	8.4	1.3	6.6	1.5	7.9	2.1	16.4	3.5
3.9	0.8	10.4	1	7.7	1.3	14.8	3.3	13.9	2.4
32.3	1.8	18.7	1.1	23.6	1.9	15.9	1.5	12.5	1.7
35.9	1.8	31.5	1.4	34	2	33.1	2.2	24.8	2.2
18.9	1.5	24.9	1	21.4	1.5	26.1	2.5	30.4	2.3
7.6	1	13	0.8	10.1	1.4	15.6	2.3	15.7	2.4
5.4	0.9	11.8	0.8	10.9	1.3	9.2	1.5	16.6	2.3

Appendix M

Estimated Energy Requirements by Body Weight Status

CONTENTS

TABLE M-7 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult Canadian Men Based on Median Height and Weight for Each Age Group

TABLE M-8 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult Canadian Women Based on Median Height and Weight for Each Age Group

UNITED STATES

TABLE M-1 Estimated Energy Requirements (EER) for Underweight, Normal Weight, Overweight, and Obese U.S. Boys Aged 3–18 Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M>I[d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
3[f]	95.6[g]	37.6	13.1	28.8	1,000	1,140	1,121	1,134
4–8	120.2	47.3	20.8	45.8	1,427	1,514	1,596	1,698
9–13	148.2	58.3	31.2	68.6	1,956	1,995	2,192	2,398
14–18	173.3	68.2	49.1	108.0	2,532	2,588	2,889	3,214
Normal weight								
3	94.9	37.4	14.3	31.5	1,006	1,158	1,137	1,151
4–8	118.1	46.5	21.3	46.9	1,406	1,506	1,580	1,677
9–13	147.0	57.9	37.1	81.6	2,018	2,104	2,297	2,517
14–18	172.3	67.8	61.9	136.2	2,687	2,839	3,138	3,496
Overweight								
3	97.7	38.5	16.9	37.2	1,077	1,235	1,226	1,255
4–8	121.2	47.7	26.2	57.6	1,511	1,632	1,719	1,839
9–13	145.6	57.3	45.6	100.3	2,112	2,264	2,454	2,693
14–18	174.9	68.9	77.6	170.7	2,927	3,179	3,493	3,901
Obese								
3	98.2	38.7	18.1	39.8	1,099	1,264	1,256	1,290
4–8	126.1	49.6	34.7	76.3	1,686	1,847	1,955	2,112
9–13	152.8	60.2	64.3	141.5	2,451	2,706	2,927	3,239
14–18	174.1	68.5	96.1	211.4	3,160	3,548	3,861	4,319

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated by age group (see note for 3 y group).

[b] Uses EER equations for boys, 3–18 y.

[c] Age used to predict EER is based on specific age: 4–8 y: 6 y; 9–13 y: 11 y; 14–18 y: 16 y.

[d] For ages 3–8 y: inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 y: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 y: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

[e] Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obese: 95th percentile and above (CDC).

[f] Note that reference heights and weights are for 2-to-3-y-old group, but equations are for ages 3–18 y, so only 3-year-olds were calculated. However, heights and weights are likely to be underestimates for 3-year-olds.

[g] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-2 Estimated Energy Requirements (EER) for Underweight, Normal Weight, Overweight, and Obese U.S. Girls Aged 3–18 Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive PAL[d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
3[f]	93.7[g]	36.9	11.2	24.6	985	1,012	1,064	1,105
4–8	117.6	46.3	18.7	41.1	1,248	1,361	1,416	1,581
9–13	149.1	58.7	27.0	59.4	1,559	1,789	1,841	2,177
14–18	161.6	63.6	42.5	93.5	1,807	2,056	2,151	2,504
Normal weight								
3	93.5	36.8	14.0	30.8	1,031	1,051	1,113	1,142
4–8	115.8	45.6	20.6	45.3	1,265	1,366	1,429	1,575
9–13	146.0	57.5	37.5	82.5	1,712	1,905	1,997	2,270
14–18	161.6	63.6	55.5	122.1	2,029	2,248	2,390	2,690
Overweight								
3	93.8	36.9	15.4	33.9	1,057	1,075	1,142	1,167
4–8	118.2	46.5	25.5	56.1	1,369	1,469	1,547	1,689
9–13	152.7	60.1	53.7	118.1	2,045	2,229	2,373	2,623
14–18	161.6	63.6	70.8	155.8	2,290	2,473	2,670	2,908
Obese								
3	95.7	37.7	17.3	38.1	1,106	1,128	1,200	1,229
4–8	122.1	48.1	32.1	70.6	1,514	1,616	1,714	1,854
9–13	152.7	60.1	66.5	146.3	2,263	2,417	2,608	2,805
14–18	161.6	63.6	88.0	193.6	2,584	2,726	2,986	3,153

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated by age group (see note for 3 y group).

[b] Uses EER equations for girls, 3–18 y.

[c] Age used to predict EER is based on specific age: 4–8 y: 6 y; 9–13 y: 11 y; 14–18 y: 16 y.

[d] For ages 3–8 y: inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 y: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 y: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

[e] Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obese: 95th percentile and above (CDC).

[f] Note that reference heights and weights are for 2-to-3-y-old group, but equations are for ages 3–18 y, so only 3-year-olds were calculated. However, heights and weights are likely to be underestimates for 3-year-olds.

[g] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-3 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult U.S. Men Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M>I[d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
19–30	176.1[f]	69.3	54.2	119.2	2,391	2,582	2,745	2,996
31–50	176.3	69.4	54.7	120.3	2,237	2,429	2,591	2,846
51–70	174.9	68.9	53.9	118.6	2,000	2,189	2,353	2,593
> 70	172.2	67.8	51.7	113.7	1,735	1,917	2,084	2,292
19+	175.4	69.1	54.3	119.5	2,117	2,307	2,471	2,716
Normal weight								
19–30	176.1	69.3	68.5	150.7	2,593	2,796	2,972	3,269
31–50	175.9	69.3	71	156.2	2,464	2,669	2,848	3,152
51–70	174.2	68.6	69.9	153.8	2,221	2,422	2,603	2,887
> 70	170.5	67.1	65.8	144.8	1,923	2,113	2,297	2,535
19+	175.1	68.9	69.3	152.5	2,327	2,529	2,708	2,998
Overweight								
19–30	176.1	69.3	83.3	183.3	2,802	3,017	3,208	3,552
31–50	175.7	69.2	84.9	186.8	2,659	2,875	3,068	3,414
51–70	174.6	68.7	83	182.6	2,408	2,621	2,814	3,144
> 70	171.3	67.4	80.1	176.2	2,130	2,334	2,530	2,820
19+	175.0	68.9	83.5	183.7	2,526	2,740	2,933	3,268
Obese								
19–30	176.2	69.4	107.2	235.8	3,139	3,375	3,588	4,010
31–50	176.9	69.6	106.9	235.2	2,977	3,214	3,426	3,853
51–70	175.3	69.0	104.2	229.2	2,712	2,943	3,156	3,560
> 70	173.2	68.2	100.3	220.7	2,427	2,651	2,863	3,236
19+	175.9	69.3	105	231.0	2,835	3,069	3,281	3,693

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated by age group.

[b] Uses EER equations for adult men.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; >70 y: 80 y; 19 y+: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

[e] Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0 (CDC).

[f] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-4 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult U.S. Women Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive MI[d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
19–30	162.7[f]	64.1	45.8	100.8	1,877	2,030	2,164	2,388
31–50	162.5	64.0	45.2	99.4	1,763	1,917	2,050	2,273
51–70	160.8	63.3	48.2	106.0	1,648	1,802	1,936	2,155
> 70	156.8	61.7	35.8	78.8	1,340	1,484	1,617	1,823
19+	161.2	63.5	47.1	103.6	1,708	1,861	1,995	2,215
Normal weight								
19–30	162.8	64.1	57.6	126.7	2,015	2,174	2,310	2,536
31–50	162.9	64.2	59.5	130.9	1,933	2,093	2,230	2,457
51–70	161.3	63.5	59.2	130.2	1,780	1,938	2,075	2,298
> 70	157.2	61.9	54.8	120.6	1,565	1,717	1,854	2,065
19+	161.8	63.7	58.4	128.5	1,844	2,002	2,139	2,362
Overweight								
19–30	162.8	64.1	71.1	156.4	2,173	2,338	2,477	2,706
31–50	162.1	63.8	71.6	157.5	2,070	2,234	2,374	2,601
51–70	160.9	63.3	70.9	156.0	1,915	2,078	2,217	2,441
> 70	156.7	61.7	67.3	148.1	1,709	1,866	2,005	2,218
19+	160.9	63.3	70.8	155.8	1,984	2,147	2,286	2,510
Obese								
19–30	162.0	63.8	94.1	207.0	2,438	2,612	2,756	2,988
31–50	162.5	64.0	94.6	208.1	2,342	2,516	2,660	2,893
51–70	160.5	63.2	91.2	200.6	2,150	2,322	2,465	2,692
> 70	157.0	61.8	83.6	183.9	1,901	2,066	2,208	2,425
19+	161.1	63.4	91.9	202.2	2,232	2,404	2,547	2,777

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For U.S. population, based on NHANES 2015–2018, estimated by age group.

[b] Uses EER equations for adult women.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y+: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

[e] Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0 (CDC).

[f] Median height values were not available for underweight group; values based on overall population heights.

CANADA

TABLE M-5 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Canadian Boys Aged 3–18 Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M>I [d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
3[f]	100.1[g]	39.4	13.6	29.9	1,065	1,189	1,188	1,215
4–8	121.0	47.6	18.5	40.7	1,407	1,474	1,559	1,656
9–13	148.3	58.4	30.7	67.5	1,951	1,986	2,183	2,388
14–18	174.7	68.8	53.4	117.5	2,606	2,687	2,995	3,336
Normal weight								
3	100.2	39.4	15.5	34.1	1,091	1,228	1,229	1,261
4–8	120.5	47.4	21.9	48.2	1,445	1,539	1,622	1,728
9–13	147.7	58.1	38.0	83.6	2,039	2,128	2,325	2,549
14–18	174.9	68.9	64.1	141.0	2,750	2,906	3,216	3,587
Overweight								
3	101.7	40.0	17.9	39.4	1,142	1,290	1,297	1,340
4–8	122.9	48.4	27.3	60.1	1,547	1,669	1,763	1,890
9–13	151.5	59.6	52.3	115.1	2,277	2,451	2,665	2,940
14–18	173.9	68.5	78.5	172.7	2,926	3,189	3,498	3,907
Obese								
3	97.0	38.2	17.8	39.2	1,080	1,247	1,235	1,265
4–8	126.1	49.6	34.0	74.8	1,677	1,833	1941	2,095
9–13	152.9	60.2	63.3	139.3	2,440	2,686	2,908	3,217
14–18	174.0	68.5	96.8	213.0	3,168	3,561	3,874	4,334

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated by age group.

[b] Uses EER equations for boys, 3–18 y.

[c] Age used to predict EER is based on specific age: 4–8 y: 6 y; 9–13 y: 11 y; 14–18 y: 16 y.

[d] For ages 3–8 y: inactive: 1.0 ≤ PAL < 1.31; low active: 1.31 ≤ PAL < 1.44; active: 1.44 ≤ PAL < 1.59; very active: 1.59 ≤ PAL < 2.5. For ages 9–13 y: inactive: 1.0 ≤ PAL < 1.44; low active: 1.44 ≤ PAL < 1.60; active: 1.60 ≤ PAL < 1.77; very active: 1.77 ≤ PAL < 2.5. For ages 14–18 y: inactive: 1.0 ≤ PAL < 1.57; low active: 1.57 ≤ PAL < 1.74; active: 1.74 ≤ PAL < 1.94; very active: 1.94 ≤ PAL < 2.5.

[e] Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obese: 95th percentile and above (CDC).

[f] Note that reference heights and weights for Canada include only 3-year-olds.

[g] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-6 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Canadian Girls Aged 3–18 Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M▸I [d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
3[f]	99.5[g]	39.2	13.2	29.0	1,068	1,116	1,169	1,240
4–8	118.7	46.7	17.8	39.2	1,242	1,362	1,412	1,588
9–13	149.5	58.9	26.5	58.3	1,553	1,787	1,837	2,177
14–18	164	64.6	43.3	95.3	1,841	2,099	2,194	2,560
Normal weight								
3	99.4	39.1	15.3	33.7	1,068	1,116	1,169	1,240
4–8	117.8	46.4	21.2	46.6	1,242	1,362	1,412	1,588
9–13	148.6	58.5	38.6	84.9	1,553	1,787	1,837	2,177
14–18	164.2	64.6	55.9	123.0	1,841	2,099	2,194	2,560
Overweight								
3	100.9	39.7	17.8	39.2	1,158	1,201	1,270	1,331
4–8	119.7	47.1	25.2	55.4	1,376	1,484	1,559	1,712
9–13	152.5	60.0	52.6	115.7	2,024	2,210	2,351	2,604
14–18	162.1	63.8	70.6	155.3	2,291	2,476	2,672	2,914
Obese								
3	98.5	38.8	20	44.0	1,176	1,203	1,282	1,318
4–8	126.3	49.7	34.1	75.0	1,584	1,699	1,800	1,959
9–13	155.6	61.3	68.3	150.3	2,318	2,481	2,675	2,884
14–18	162.4	63.9	86.5	190.3	2,565	2,714	2,967	3,146

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated by for age group.

[b] Uses EER equations for girls, 3–18 y.

[c] Age used to predict EER is based on specific age: 4–8 y: 6 y; 9–13 y: 11 y; 14–18 y: 16 y.

[d] For ages 3–8 y: inactive: $1.0 \leq PAL < 1.31$; low active: $1.31 \leq PAL < 1.44$; active: $1.44 \leq PAL < 1.59$; very active: $1.59 \leq PAL < 2.5$. For ages 9–13 y: inactive: $1.0 \leq PAL < 1.44$; low active: $1.44 \leq PAL < 1.60$; active: $1.60 \leq PAL < 1.77$; very active: $1.77 \leq PAL < 2.5$. For ages 14–18 y: inactive: $1.0 \leq PAL < 1.57$; low active: $1.57 \leq PAL < 1.74$; active: $1.74 \leq PAL < 1.94$; very active: $1.94 \leq PAL < 2.5$.

[e] Underweight: < 5th percentile of BMI for age; normal weight: 5th percentile to < 85th percentile; overweight: 85th percentile to < 95th percentile; obese: 95th percentile and above (CDC).

[f] Note that reference heights and weights for Canada include only 3-year-olds.

[g] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-7 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult Canadian Men Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M▸I [d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
19–30	178.4[f]	70.2	54.6	120.1	2,412	2,607	2,766	3,040
31–50	176.4	69.4	53.9	118.6	2,226	2,418	2,579	2,833
51–70	174.5	68.7	—	—	—	—	—	—
> 70	171.5	67.5	—	—	—	—	—	—
19+	175.9	69.3	54.6	120.1	2,125	2,316	2,479	2,730
Normal weight								
19–30	177.6	69.9	70.8	155.8	2,635	2,843	3,018	3,337
31–50	176.7	69.6	72.0	158.4	2,484	2,691	2,869	3,183
51–70	174.4	68.7	70.2	154.4	2,227	2,428	2,609	2,896
> 70	172.7	68.0	69.0	151.8	1,982	2,179	2,362	2,630
19+	176.4	69.4	71.0	156.2	2,359	2,565	2,743	3,051
Overweight								
19–30	179.0	70.5	87.2	191.8	2,875	3,099	3,289	3,672
31–50	176.0	69.3	84.1	185.0	2,650	2,866	3,057	3,403
51–70	174.6	68.7	83.2	183.0	2,411	2,624	2,817	3,148
> 70	170.7	67.2	80.9	178.0	2,137	2,341	2,539	2,826
19+	175.7	69.2	84.2	185.2	2,541	2,756	2,949	3,292
Obese								
19–30	179.9	70.8	106.3	233.9	3151	3,392	3,598	4,051
31–50	176.6	69.5	103.3	227.3	2924	3,157	3,367	3,780
51–70	174.3	68.6	100.6	221.3	2655	2,881	3,092	3,476
> 70	171.7	67.6	97.1	213.6	2372	2,591	2,803	3,152
19+	175.7	69.2	102.6	225.7	2800	3,031	3,241	3,644

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated by for age group.

[b] Uses EER equations for adult men.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70y: 80 y; 19 y+: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

[e] Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0 (CDC).

[f] Median height values were not available for underweight group; values based on overall population heights.

TABLE M-8 Estimated Energy Requirements (EER) for Overall Population, Underweight, Normal Weight, Overweight, and Obese Adult Canadian Women Based on Median Height and Weight for Each Age Group

	Reference Values[a]				EER (kcal/d)[b]			
Age Group[c] (y)	Height (cm)	Height (in.)	Weight (kg)	Weight (lb)	Inactive M>I[d]	Low Active PAL	Active PAL	Very Active PAL
Underweight[e]								
19–30	163.4[f]	64.3	43.9	96.6	1858	2012	2145	2370
31–50	163.2	64.3	50.0	110.0	1824	1979	2114	2340
51–70	160.4	63.1	41.1	90.4	1563	1713	1846	2062
> 70	157.8	62.1	40.7	89.5	1403	1551	1684	1893
19+	162.1	63.8	44.7	98.3	1685	1838	1971	2193
Normal weight								
19–30	163.9	64.5	59.2	130.2	2040	2201	2337	2567
31–50	163.4	64.3	58.6	128.9	1925	2085	2222	2449
51–70	161.0	63.4	58.2	128.0	1767	1924	2061	2282
> 70	157.6	62.0	57.2	125.8	1595	1750	1886	2099
19+	162.3	63.9	58.5	128.7	1848	2007	2143	2368
Overweight								
19–30	162.2	63.9	71.4	157.1	2174	2338	2477	2705
31–50	163.0	64.2	71.8	158.0	2078	2243	2382	2612
51–70	160.4	63.1	70.0	154.0	1901	2064	2202	2425
> 70	158.3	62.3	69.5	152.9	1743	1903	2042	2260
19+	161.5	63.6	70.7	155.5	1986	2149	2288	2514
Obese								
19–30	164.4	64.7	97.1	213.6	2487	2664	2808	3047
31–50	163.3	64.3	93.9	206.6	2338	2513	2657	2892
51–70	160.3	63.1	89.5	196.9	2129	2300	2442	2669
> 70	156.7	61.7	81.5	179.3	1875	2039	2180	2396
19+	162.1	63.8	90.9	200.0	2226	2399	2542	2773

NOTE: cm = centimeter; d = day; in. = inch; lb = pound; kcal = kilocalorie; kg = kilogram; PAL = physical activity level; y = year.

[a] For Canadian population, based on CHMS 2012–2019, estimated by for age group.

[b] Uses EER equations for adult women.

[c] Age used to predict EER is based on specific age: 19–30 y: 25 y; 31–50 y: 40 y; 51–70 y: 60 y; > 70 y: 80 y; 19 y+: 50 y.

[d] Inactive: 1.0 ≤ PAL < 1.53; low active: 1.53 ≤ PAL < 1.69; active: 1.69 ≤ PAL < 1.85; very active: 1.85 ≤ PAL < 2.5.

[e] Underweight: BMI < 18.5; normal weight: BMI 18.5 to < 25; overweight: BMI 25.0 to < 30; obesity: BMI ≥ 30.0 (CDC).

[f] Median height values were not available for underweight group; values based on overall population heights.