A population-based approach to define body-composition phenotypes[1–3]

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ABSTRACT

Background: Abnormal body compositions such as high adiposity (HA), low muscle mass (LM), or a combination of the 2 [high adiposity with low muscle mass (HA-LM)] are relevant phenotypes, but data on their prevalence and impact on health are still limited. This is largely because of a lack of a consensus definition for these conditions. Of particular interest is the HA-LM phenotype, also termed "sarcopenic obesity," which may confer greater health risk.

Objective: We propose a new approach for operationalizing abnormal body-composition phenotypes in a representative adult population.

Design: Whole-body dual-energy X-ray absorptiometry data obtained from the 1999–2004 NHANES were analyzed for 13,236 subjects aged ≥18 y (maximum weight and height of 136 kg and 1.96 m, respectively). Sex- and body mass index (BMI)–specific decile groups of appendicular skeletal muscle index (ASMI; kg/m^2) and fat mass index (FMI; kg/m^2) were developed. Cutoffs for HA and LM were incorporated into a diagnostic framework to characterize 4 specific body-composition phenotypes—low adiposity with high muscle mass, high adiposity with high muscle mass, low adiposity with low muscle mass, and HA-LM—and a subclassification of the phenotypes into classes I, II, and III.

Results: Abnormal phenotypes were prevalent across the age spectrum and BMI categories. The association between ASMI or FMI and age was modified by sex and BMI. The prevalence of HA-LM in the whole sample was 10.3% in women and 15.2% in men. The prevalence of all subclasses of HA-LM in obese women and men was 14.7% and 22.9%, respectively. HA-LM class III was more prevalent in obese men (2.3%) than in obese women (0.3%).

Conclusions: We developed sex- and BMI-specific reference curves to harmonize the classification of body-composition phenotypes. The application of this classification will be particularly useful in the identification of cases of sarcopenic obesity. The association of these phenotypes with metabolic deregulation and increased disease risk awaits verification. *Am J Clin Nutr* 2014;99:1369–77.

INTRODUCTION

Aging is associated with gradual changes in body composition and reciprocal modifications of fat and lean body mass. More significant deviations from normal, healthy body-composition trajectories configure the development of abnormal phenotypes such as high adiposity (HA)[4], low muscle mass (LM), or a combination of the 2 [high adiposity with low muscle mass (HA-LM)].

Although BMI and waist circumference have been somewhat helpful as surrogate measures of nutritional assessment in clinical practice, their predictive ability to discriminate between body-composition phenotypes is relatively poor, and alternative, more accurate tools are needed to assess nutritional status and predict disease risk.

LM is linked to important health consequences and elevated health care costs (1, 2). LM has mostly been studied in the context of severe muscle depletion (sarcopenia) that occurs with aging and catabolic conditions such as cancer (3). The diagnosis of LM is still heterogeneous across studies. Adiposity, similar to muscle mass, can be measured by using different body-composition techniques, although surrogate measures of excess weight, such as BMI (in kg/m^2; ≥25), are often used in clinical settings. Undoubtedly, excess adiposity is associated with higher risk of cardiovascular disease, diabetes, and hypertension, among others (4, 5).

Increasing evidence suggests that the concurrent presence of HA-LM may be associated with a more elevated health risk (6–12). The additive effects of abnormal muscle and adipose tissue content in an individual may lead to greater propensity for metabolic and cardiovascular deregulation, which has been conveyed into the proposal of a new diagnostic entity termed

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[4] Abbreviations used: ASMI, appendicular skeletal muscle mass index; DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FMI, fat mass index; HA, high adiposity; HA-HM, high adiposity with high muscle mass; HA-LM, high adiposity with low muscle mass; LA-HM, low adiposity with high muscle mass; LA-LM, low adiposity with low muscle mass; LM, low muscle mass; LST, lean soft tissue; UW-NW, underweight and normal weight.

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"sarcopenic obesity" (13, 14). Despite the growing interest in understanding this body-composition phenotype, a diagnostic consensus still has not been reached, as is evident in the contrasting results reported in the medical literature (6). Additional limitations reside in the age and body mass dependency of the current sarcopenic obesity concept because current criteria also have not taken into consideration the strong association between body-composition components (adiposity and muscle mass) and total body mass, with cutoffs derived from normal-weight populations. Therefore, the discriminative accuracy of current criteria may be limited and has a considerable impact on the specificity of the classification of this body-composition phenotype.

In addition, sarcopenic obesity has been investigated from an aging perspective and discussion of the potential clinical implications is limited to older individuals. The life-course trajectory of this phenotype has therefore been overlooked, and diagnostic criteria in young and middle-aged subjects are missing. Likewise is the prevalence of this phenotype across the BMI spectrum, in which normal-weight individuals would not necessarily be considered "sarcopenic obese" but who certainly may present with an HA-LM phenotype.

Here we attempt to address these limitations by developing sex- and BMI-specific reference curves for appendicular skeletal muscle index (ASMI) and fat mass index (FMI) in a representative adult population on the basis of dual-energy X-ray absorptiometry (DXA) measurements of body composition. Diagnostic cutoffs for HA and LM will be incorporated into the diagnostic framework previously proposed by Baumgartner (8) to characterize the following 4 specific body-composition phenotypes: low adiposity with high muscle mass (LA-HM), high adiposity with high muscle mass (HA-HM), low adiposity with low muscle mass (LA-LM), and HA-LM.

SUBJECTS AND METHODS

The NHANES is a program designed to assess the health and nutritional status of adults and children in the United States. NHANES cross-sectional data collected from 1999 to 2004 were used in this study. These include data on age-, sex-, and ethnicity-specific DXA-assessed body-composition values in 16,383 non-Hispanic whites (hereafter referred to as "white"), Mexican American, and non-Hispanic African American individuals. These DXA data sets are released by NHANES on the CDC website (http://www.cdc.gov/nchs/about/major/nhanes/dxx/dxa.htm).

Subjects

A complex multistage probability sampling method was used to enroll individuals into NHANES, including oversampling of African Americans, Mexican Americans, low-income whites, and older subjects (≥60 y) to produce reliable statistics (15). All procedures took into account the complex survey design of NHANES with the use of sample weights, cluster and stratification values, and survey procedures in SAS (SAS Institute) or SUDAAN (RTI International) as described in NHANES documentation (16).

The survey included household interviews and detailed physical examinations obtained in mobile examination centers. Approval for NHANES 1999–2004 was obtained from the National Center for Health Statistics institutional review board. Patients were excluded from the analysis if their reported weight exceeded the DXA scan table weight limit of 136 kg or if their reported height was greater than the DXA scan table length of 196 cm. Women were excluded from the DXA examination if a pregnancy test was positive at examination time or if they said they were pregnant (17).

Anthropometric and body-composition measurements

Height was measured by using a stadiometer after deep inhalation. Weight was measured by using an electronic digital scale calibrated in kilograms. BMI was calculated as weight (kg) divided by height (m) squared.

Body-composition variables included whole-body DXA measurements of fat mass and lean soft tissue (LST). LST assessed by DXA is composed of all fat-free mass (FFM) components except for bone mineral content. Therefore, it reflects the sum of total body water, total body protein, carbohydrate, nonfat lipid, and soft tissue minerals. The above measurements were also available for a number of segmental regions, including the head, arms, legs, trunk, pelvic regions, subtotal of the whole body (excluding only the head), and the whole body. From these whole-body measures the following derivative values were calculated: FMI (fat mass/height^2) and ASMI (appendicular lean mass/height^2) (18, 19). Appendicular skeletal muscle reflects the LST from arms and legs, which is mainly muscle (except for a small amount of connective tissue and skin) (19). LST index (LST/height^2) and FFM (LST + bone mineral mass) index (FFM/height^2) were also reported.

The whole-body DXA scans in NHANES were acquired by using a QDR 4500A fan beam densitometer (software version 12.1 in its default configuration; Hologic Inc). A detailed description of data acquisition and precision is found elsewhere (20–23).

Classification of body-composition phenotypes

The identification of body-composition phenotypes according to different amounts of muscularity and adiposity was based on the approach proposed by Baumgartner (8) (**Figure 1**). The revised classification proposes a BMI and sex stratification of the population to identify specific cutoffs for the definition of the 4 body-composition phenotypes: LA-HM, HA-HM, LA-LM, and HA-LM. The cutoffs were defined according to the following deciles: LA-HM (ASMI: 50–100; FMI: 0–49.99); HA-HM (ASMI: 50–100; FMI: 50–100); LA-LM (ASMI: 0–49.99; FMI: 0–49.99), and HA-LM (ASMI: 0–49.99; FMI: 50–100). A subclassification for each body-composition phenotype was proposed by including 3 categories—class I, class II, and class III, as shown in Supplemental Table S1 under "Supplemental data" in the online issue—to depict progressive changes/abnormalities within each phenotype. The HA-LM cutoffs were as follows: class I (ASMI: 0–49.99; FMI: 50–59.99; or ASMI: 40–49.99; FMI: 60–100), class II (ASMI: 0–39.99; FMI: 60–79.99; or ASMI: 20–39.99; FMI: 80–100), and class III (ASMI: 0–19.99; FMI: 80–100). The cutoffs for the other body-composition phenotypes are presented in Supplemental Table S1 under "Supplemental data" in the online issue. The proposed

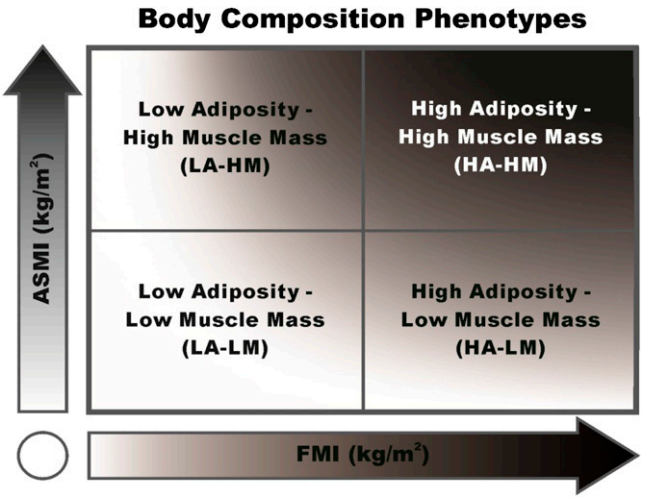

FIGURE 1. Body-composition phenotype classification criteria by decile groups of ASMI and FMI based on Baumgartner (8). In this figure, body composition is depicted by a spectrum of ASMI and FMI (low to high). On the basis of the Baumgartner model (8), these phenotypes can be depicted as follows: low adiposity with high muscle mass (individuals with low FMI and high ASMI), high adiposity with high muscle mass (individuals with high FMI and ASMI), low adiposity with low muscle mass (individuals with low ASMI and FMI), and those with high adiposity with low muscle mass (individuals with high FMI and low ASMI). A subclassification for each group was proposed by including 3 categories—class I, class II, and class III—as described in Supplemental Table S1 under "Supplemental data" in the online issue to depict progressive changes/abnormalities within each phenotype. Cutoffs were defined according to the following deciles: LA-HM (ASMI: 50–100; FMI: 0–49.99), HA-HM (ASMI: 50–100; FMI: 50–100), LA-LM (ASMI: 0–49.99; FMI: 0–49.99), and HA-LM (ASMI: 0–49.99; FMI: 50–100). ASMI, appendicular skeletal muscle mass index; FMI, fat mass index; HA-HM, high adiposity with high muscle mass; HA-LM, high adiposity with low muscle mass; LA-HM, low adiposity with high muscle mass; LA-LM, low adiposity with low muscle mass.

classification aims to operationalize the large variability in body-composition phenotypes by taking into account the individual effects of age, sex, and body mass on body components.

Statistical analysis

Anthropometric means and SEs were evaluated by using the survey means procedure in SAS version 9.3, whereas the DXA-derived means and SEs were calculated by using SUDAAN version 10. The final data set included a total of 13,236 white, African American, or Mexican American nonpregnant subjects aged ≥18 y who were not missing BMI or DXA-measured fat mass. The total adult sample (age range: 18–85 y) was stratified by sex (men, women) and BMI. BMI categories were as follows: underweight and normal weight (UW-NW; ≤24.9); overweight (25.0–29.9), and obese (≥30.0) (24). The UW-NW categories were combined as well as the obese and morbidly obese categories because of limited sample size. We have not stratified our population by ethnicity. Previous work in the same cohort has shown that FMI classification ranges were similar across the 3 ethnic groups regardless of the wide variability in BMI classification (20).

A curve-fitting procedure called LMS (lmsChartMaker ProVersion 2.54) (25) was used to generate the reference curves accounting for skewness of the variables. The underlying reference data are normalized by dividing the independent measure (eg, age) into groups and then applying a power transformation to eliminate the skewness of the dependent variable. A smooth curve is fitted to the normalizing power transformation for each age group, generating an optimum ''L'' (power) curve that normalizes the dependent measure over the entire age range. The procedure also fits median (M) and CV (S) curves, and these 3 curves (L, M, and S) fully describe the reference data. We reported sex- and BMI-specific deciles for ASMI and FMI. The z scores for each individual value of the 2 body-composition ratios can also be calculated by using the following equation:

$$Z = \frac{M[(X \div M)^L - 1]}{L\sigma} \quad (1)$$

where X is the body-composition ratio (eg, ASMI or FMI), L is the power transformation, M is the median value, and σ (S × M) is the population SD.

The analysis data set used to create reference curves included the average of the 5 DXA imputations available from NHANES and the appropriate sample weight for each observation. The LMS software is capable of incorporating the sample weights into the curve-fitting procedure, and the observations were fitted by selecting more parsimonious models over more complex models as long as the goodness of fit was similar (ie, we tried to avoid overfitting the curves). To avoid creating differences through modeling, the L, M, and S values were selected by using the entire sample and then applied to each sex and BMI stratification. Furthermore, we used careful visual inspection of the Q statistic, a plot of standardized residuals in which the data are split into groups and the nonrandom between-group variations in the estimated moments of the z scores are plotted against the equivalent *df* used to fit the curve. The Q statistic was considered satisfactory at or below an ideal value of 2 for the L, M, and S curves (some may have reached 4) and if the fitted curve was reasonably smooth and plausible for the data being fitted, as recommended by the developers of LMS (25).

The LMS software was then used to export the decile cutoffs separately for FMI and ASMI by sex, BMI category, and age in years. These values were merged with the original data set so that each observation was grouped into a decile category according to the subjects' sex, age, BMI category, and FMI or ASMI. If a body-composition value was less than a decile cutoff but greater than or equal to the previous one, it was labeled according to the upper cutoff (ie, an FMI >40th percentile cutoff and <50th percentile cutoff was grouped in the 50th percentile). The prevalence of each combination of FMI and ASMI decile category was calculated by using a survey frequency procedure that included the sample weights, clustering, and stratification values.

RESULTS

Descriptive characteristics of study participants are shown in **Table 1**. On the basis of a weighted frequency analysis, the percentages of different ethnic groups were 79.7% white, 8.2% Mexican American, and 12.1% African American. Reference curves for ASMI and FMI used for the diagnosis of LA-HM, LA-LM, HA-HM, and HA-LM individuals are presented in **Figures 2–5**; the ASMI and FMI decile values for the male and female groups are reported in Supplemental Tables S2–S17 under "Supplemental data" in the online issue.

TABLE 1
Descriptive characteristics of subjects[1]

	All		UW-NW		Overweight		Obese	
	Men	Women	Men	Women	Men	Women	Men	Women
n	6656	6580	2308	2347	2648	1953	1700	2280
Age (y)	44.57 ± 0.33[2]	46.8 ± 0.36	40.64 ± 0.47	43.79 ± 0.47	46.29 ± 0.39	49.45 ± 0.58	46.67 ± 0.61	48.15 ± 0.45
Weight (kg)	85.87 ± 0.19	73.96 ± 0.35	70.18 ± 0.23	58.44 ± 0.17	85.59 ± 0.18	72.33 ± 0.16	104.99 ± 0.41	93.89 ± 0.41
Height (cm)	176.48 ± 0.12	162.55 ± 0.11	176.67 ± 0.23	163.23 ± 0.14	176.37 ± 0.17	162.46 ± 0.17	176.39 ± 0.25	161.81 ± 0.2
BMI (kg/m^2)	27.54 ± 0.07	27.99 ± 0.13	22.44 ± 0.04	21.91 ± 0.05	27.46 ± 0.04	27.36 ± 0.04	33.72 ± 0.1	35.8 ± 0.15
FM (kg)	24.67 ± 0.12	30.56 ± 0.25	15.91 ± 0.12	20.08 ± 0.15	24.36 ± 0.13	29.82 ± 0.12	35.59 ± 0.24	43.7 ± 0.28
LST (kg)	59.23 ± 0.12	41.93 ± 0.13	52.35 ± 0.18	36.97 ± 0.1	59.29 ± 0.15	41.08 ± 0.13	67.33 ± 0.24	48.58 ± 0.19
FMI (kg/m^2)	7.92 ± 0.04	11.58 ± 0.09	5.09 ± 0.04	7.54 ± 0.05	7.82 ± 0.04	11.29 ± 0.04	11.44 ± 0.07	16.67 ± 0.1
LSTI (kg/m^2)	18.98 ± 0.04	15.85 ± 0.05	16.73 ± 0.04	13.85 ± 0.03	19.02 ± 0.04	15.54 ± 0.04	21.61 ± 0.06	18.52 ± 0.06
FFM (kg)	61.95 ± 0.13	44.03 ± 0.13	54.92 ± 0.19	38.97 ± 0.1	62.03 ± 0.16	43.17 ± 0.14	70.19 ± 0.25	50.81 ± 0.19
FFMI (kg)	19.85 ± 0.04	16.65 ± 0.05	17.56 ± 0.04	14.6 ± 0.03	19.9 ± 0.04	16.32 ± 0.04	22.53 ± 0.06	19.37 ± 0.06
ASM (kg)	26.53 ± 0.08	17.76 ± 0.08	23.47 ± 0.12	15.38 ± 0.06	26.58 ± 0.09	17.28 ± 0.08	30.09 ± 0.13	21.03 ± 0.1
ASMI (kg/m^2)	8.5 ± 0.03	6.71 ± 0.03	7.5 ± 0.03	5.75 ± 0.02	8.52 ± 0.03	6.53 ± 0.03	9.65 ± 0.03	8.01 ± 0.04
WC (*n*)	6507	6391	2259	2282	2600	1901	1648	2208
WC (cm)	98.57 ± 0.2	92.77 ± 0.36	85.12 ± 0.21	79.10 ± 0.22	98.92 ± 0.2	92.88 ± 0.27	114.23 ± 0.33	109.15 ± 0.34

[1] ASM, appendicular skeletal muscle mass; ASMI, appendicular skeletal muscle mass index (adjusted by height in meters squared); FFM, fat-free mass (lean soft tissue + bone mineral content); FFMI, fat-free mass index (adjusted by height in meters squared); FM, fat mass; FMI, fat mass index (adjusted by height in meters squared); LST, lean soft tissue; LSTI, lean soft tissue index (adjusted by height in meters squared); UW-NW, underweight and normal weight; WC, waist circumference.

[2] Mean ± SE (all such values).

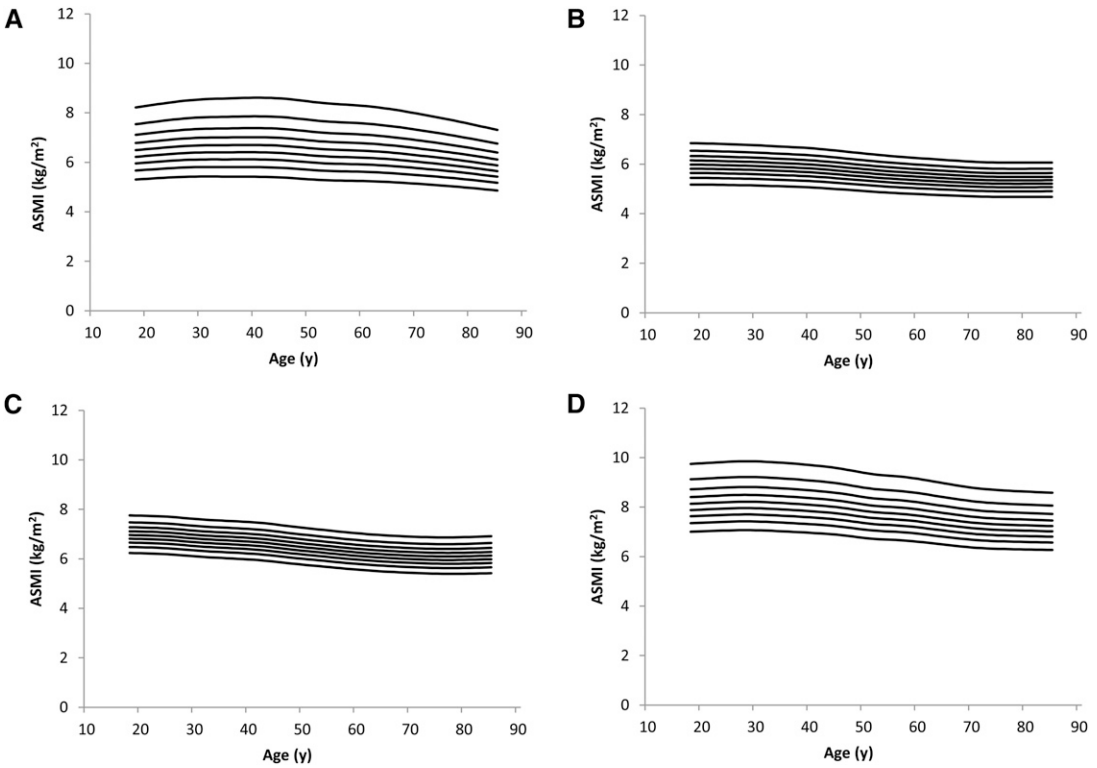

FIGURE 2. Reference curves of ASMI deciles for women in the whole population (A) and stratified by BMI in underweight and normal-weight (B), overweight (C), and obese (D) individuals. ASMI, appendicular skeletal muscle mass index.

ASMI decile curves

The association between ASMI and age was modified by sex and BMI. In all women (Figure 2), ASMI remained fairly stable throughout adulthood and began to decline around the age of 45 y, accelerating after the age of 50 y, and with even greater declines in those older than 70 y. This pattern of change in ASMI was also observed in UW-NW individuals, although the ASMI appeared to stabilize after age 70 y but with a small increase in overweight individuals in the same age group. Nonetheless, in obese individuals, a greater decline of ASMI was observed throughout the age spectrum. Compared with women, men presented with a sharper decline in ASMI with aging (Figure 3), which appeared to begin at approximately age 30 y, which occurred in all BMI categories and to a greater extent in obese individuals.

FMI decile curves

A sharp increase in FMI until the age of 60 y was observed in all women (Figure 4), after which FMI began to decline. The stratification by BMI indicated that the same pattern was observed in UW-NW women, although the increase was greater after age 50 y. In overweight women, an increase in FMI was observed between 40 and 60 y, after which FMI seemed to be relatively stable for the next decade (60–70 y), followed by a decline in older individuals.

In all men, FMI increased with age but decreased after the age of 70 y (Figure 5). In UW-NW and overweight individuals increases in FMI were associated with age. Nonetheless, in obese individuals, a decline in FMI was observed beginning at younger ages until ~45 y, after which increases in FMI were observed. In all groups, a peak in FMI appeared to occur at approximately the age of 60 y.

The sex- and BMI-specific tables used to derive the respective prevalence of body-composition phenotypes are shown in the Supplemental Tables S18–S25 under "Supplemental data" in the online issue. A summary of prevalence rates of the HA-LM body-composition phenotype for women and men is shown in **Figure 6**, A and B, respectively. The prevalence of HA-LM in the entire sample was 10.3% in women and 15.2% in men. Among UW-NW individuals, the prevalence of HA-LM (all subcategories combined) was ~23% in both men and women. However, the prevalence of HA-LM in both male and female obese groups was low (<3%). The prevalence of class I, class II, and class III HA-LM by BMI category was similar between men and women, except for obese men who were characterized by a greater prevalence of classes II and III HA-LM compared with obese women (Supplemental Tables S20–S24 under "Supplemental data" in the online issue).

DISCUSSION

This study is the first to propose sex- and BMI-specific reference curves for ASMI and FMI in a nationally representative adult population. From a methodologic perspective, our classification system is easy to interpret and clearly describes 4 categories of body composition—LA-HM, HA-HM, LA-LM, and HA-LM—plus the subcategories of HA-LM (class I, class II, and class III). Our adapted quadrant analysis approach (8) harmonizes the diagnostic approach of abnormal body composition by providing sex- and BMI-specific diagnostic groups. The theory that underlies this methodology is that risk lies on a continuum and, within each quadrant, a progressive deviation from normality of each body-composition phenotype

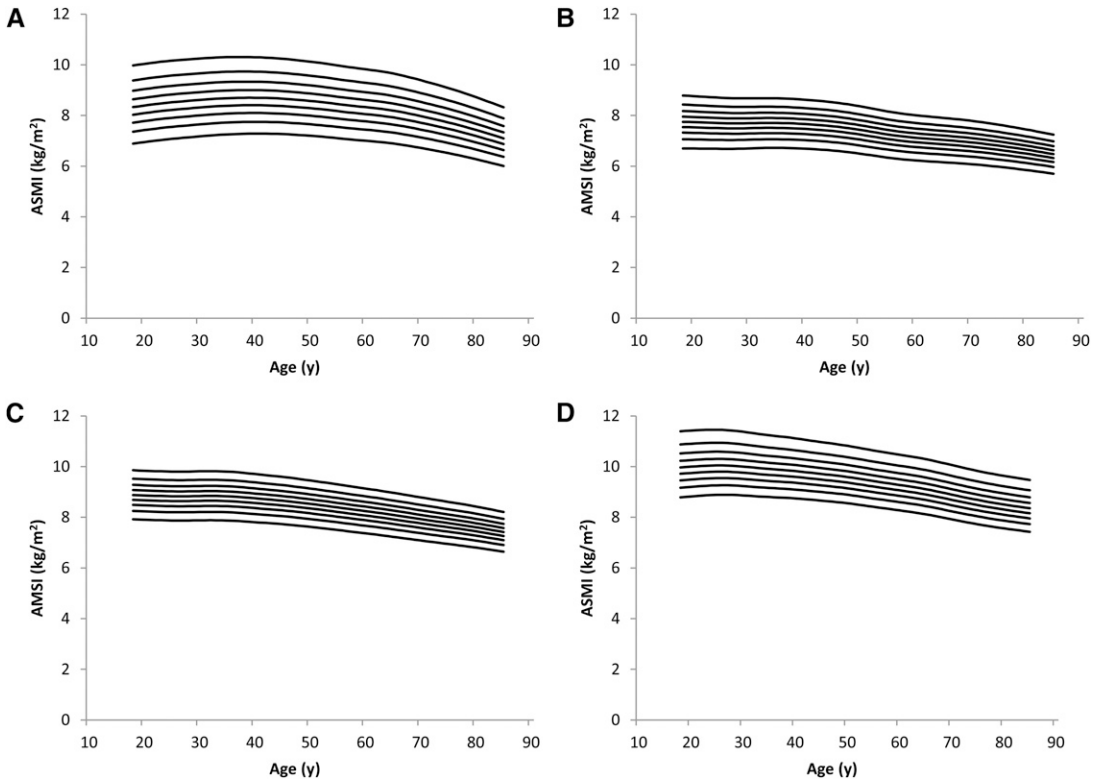

FIGURE 3. Reference curves of ASMI deciles for men in the whole population (A) and stratified by BMI in underweight and normal-weight (B), overweight (C), and obese (D) individuals. ASMI, appendicular skeletal muscle mass index.

is expected. Although our focus was the HA-LM phenotype, our subclassification approach allows for identification of other "extreme" phenotypes categorized as class III within each body-composition category such as body builders, sumo wrestlers, individuals with anorexia, and long-distance runners.

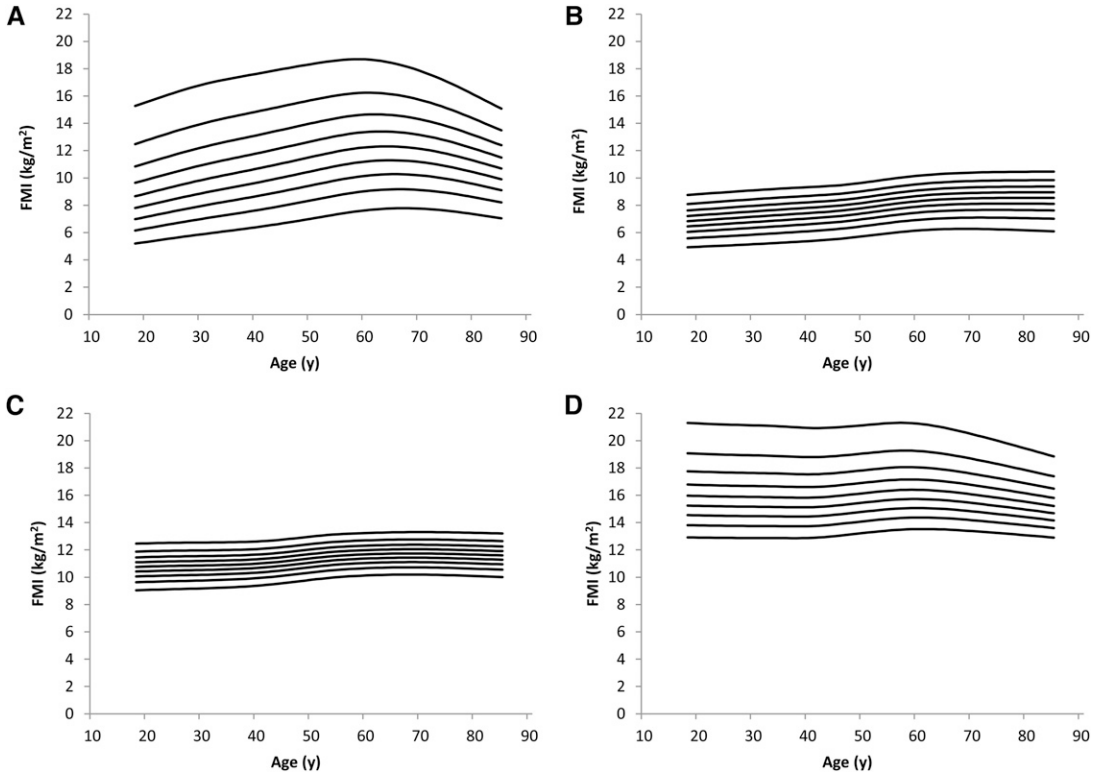

FIGURE 4. Reference curves of FMI deciles for women in the whole population (A) and stratified by BMI in underweight and normal-weight (B), overweight (C), and obese (D) individuals. FMI, fat mass index.

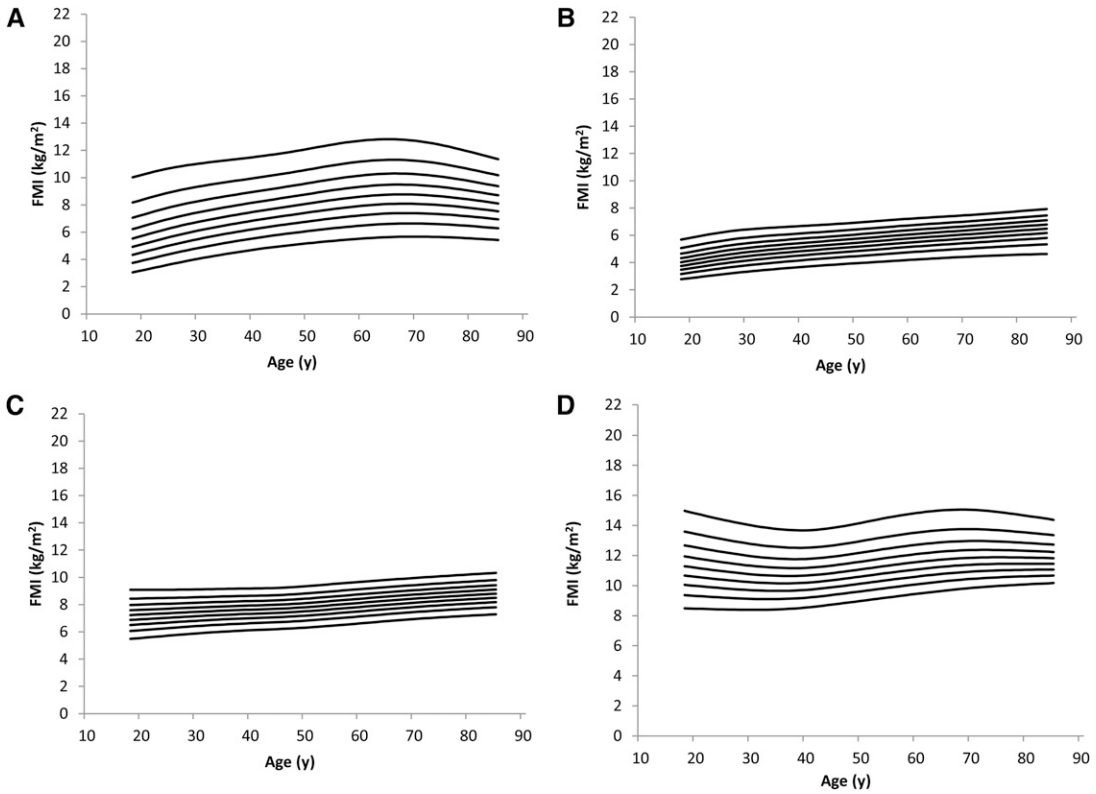

FIGURE 5. Reference curves of FMI deciles for men in the whole population (A) and stratified by BMI in underweight and normal-weight (B), overweight (C), and obese (D) individuals. FMI, fat mass index.

Our results show that variability in body-composition phenotypes was prevalent at different ages and across BMI categories. Indeed, individuals who would be classified as normal/no risk by common criteria (ie, normal BMI) may present with HA-HM, LA-LM, or HA-LM. The prevalence of abnormal body-composition phenotypes in individuals with normal BMI has important epidemiologic implications. Not only is the prevalence of obesity increasing but the concurrent aging of our population places these individuals at risk of a vicious cycle of progressive gains in fat and losses in muscle (7), potentially giving rise to an HA-LM phenotype, with implications to the public health system that we have yet to grasp. As shown by Choi et al (26), these individuals could be considered "metabolically obese, normal-weight" because they are likely to present with metabolic disturbances characteristic of obesity. Importantly, our study proposes the addition of this category of abnormal body-composition phenotype into a diagnostic group, providing criteria for future studies investigating the prevalence and health-related consequences of this phenotype. The mechanisms leading to the development of the HA-LM phenotype are largely unidentified. Intramuscular adipose tissue increases with body fat gain and may affect the secretion of "adipokines" and "myokines" influencing inflammatory and metabolic pathways, which may affect muscular metabolic flexibility and functional capacity (27, 28).

The detection of the HA-LM phenotypes at younger ages also contextualizes the need for personalized treatment interventions, in which weight-loss strategies (eg, lifestyle, dietary) would be targeted at minimizing nitrogen losses that occur during negative energy balance—a problem that has been largely ignored among young individuals attempting to lose weight (29). Our results highlight the importance of tailored interventions for optimal body-composition changes that augment fat mass losses with a relative preservation or increase in muscle mass. From a nutritional perspective, diets providing a lower carbohydrate to protein ratio are promising and are considered a priority research agenda (30). Along the same lines, aggressive treatments such as very-low-calorie diets or bariatric surgery are more frequently used in younger groups and therefore the stratification before treatment may direct the postintervention nutritional assessment and support.

Our findings also highlight the importance of the science of nutritional assessment, which emphasizes that measurements of body composition are fundamental for individual risk stratification. We are now in an era in which more sophisticated tools are needed for reliable measurements of physiologic reserves and where any superficial and subjective assessment may neglect risk and status. As an example, evaluating weight change (primarily weight loss) throughout the course of a clinical condition has been a paramount endpoint for the assessment of nutritional status and is, in fact, useful when drastic changes are observed. Nonetheless, as shown by our results, body weight (and hence BMI) may not accurately depict specific shifts between muscle and fat tissue compartments, and individuals may therefore present with weight stability while gaining fat and losing muscle mass. This disparate behavior of muscle and fat reflects the variability of body composition in our contemporary population. Because other medical fields have evolved to using sophisticated techniques, we also advocate for the use of advanced body-composition methodology for the assessment of health status of patients, expanding beyond simple measurements of body weight. It is clear from emerging studies that body composition

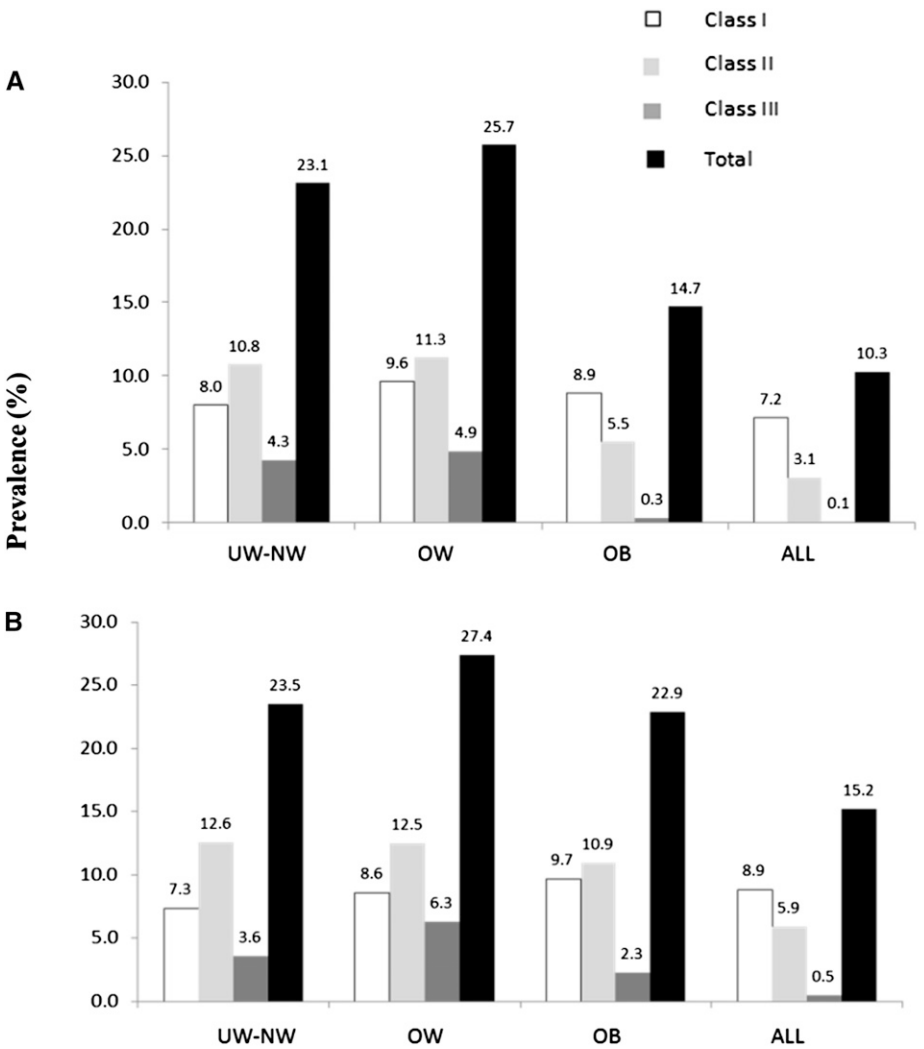

FIGURE 6. Summary of prevalence rates of HA-LM and its subcategories by BMI category in women (A) and men (B). Class I (ASMI: 0–49.99; FMI: 50–59.99; or ASMI: 40–49.99; FMI: 60–100), class II (ASMI: 0–39.99; FMI: 60–79.99; or ASMI: 20–39.99; FMI: 80–100), and class III (ASMI: 0–19.99; FMI: 80–100), as shown in Supplemental Table S1 under "Supplemental data" in the online issue. ASMI, appendicular skeletal muscle mass index; FMI, fat mass index; HA-LM, high adiposity with low muscle mass; OB, obese; OW, overweight; UW-NW, underweight and normal weight.

will be vital for identifying/planning treatment decisions, survival outcomes, and quality of life of different groups.

With regard to sex-specific differences, the prevalence of class III HA-LM in obese men was greater than in women (2.3% compared with 0.3%, respectively), which may suggest that obese men are at greater risk of developing extreme body-composition phenotypes. In fact, the pattern of greater ASMI loss in men (Figure 3) suggests a greater risk of developing LM and hence sarcopenia, which has been previously reported (18, 31, 32). Likewise, the concurrent increase in FMI observed in men would make them particularly prone to presenting with sarcopenic obesity, which is also in accordance with most studies that report higher prevalence rates of sarcopenic obesity in elderly men compared with women, as summarized by Waters and Baumgartner (33).

The pattern of FMI changes observed in the overall population (both men and women) is also similar to previous studies (34); we reported a peak amount of body fat occurring in late middle age (sixth decade of life), followed by a decline in older age. Of interest, our additional analysis of patterns of change by BMI showed that obese men were more likely to lose ASMI and gain FMI, which may translate into greater prevalences and health-related outcomes conferred by HA-LM. This remains to be confirmed in longitudinal studies.

Limitations of this study include its cross-sectional design and DXA-related constraints such as exclusion of patients >136 kg and >196 cm. Likewise, DXA assumptions of constant hydration and tissue density must be taken into account for the application of the ASMI and FMI cutoffs herein proposed. Furthermore, NHANES DXA is instrument specific (Hologic) and used adjustments proposed by Schoeller et al (23), which limits generalization to a different manufacturer. We urge DXA manufacturers to coordinate DXA calibration (ie, universal calibration) to allow comparison of measurements between different machines. Finally, the limited number of underweight and morbidly obese subjects did not allow for the development of reference curves for this group, and they were therefore grouped in the UW-NW and obese categories, respectively, to preserve representativeness of the reference curves.

Finally, our results indicate that abnormal body composition is present across the BMI spectrum and suggest possible sex differences in the physiologic mechanisms influencing body-composition

trajectories, with potential notable implications for risk stratification and prevention/treatment strategies. Here, we chose variables of particular interest in the diagnosis of obesity, sarcopenia, and sarcopenic obesity—that is, DXA-assessed ASMI and FMI—and provide valuable nationally representative data for sex- and BMI-specific classification of abnormal body-composition phenotypes.

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Errata

Erratum for Prado et al. A population-based approach to define body-composition phenotypes. Am J Clin Nutr 2014;99:1369–77.

Tables S7–S17 in the Online Supporting Material had incorrect numbers listed in them for the decile values of fat mass and appendicular skeletal muscle mass utilizing the LMS statistical procedure. Corrected tables have been provided.

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