

## INVITED REVIEW

# Body composition and morphological assessment of nutritional status in adults: a review of anthropometric variables

A. M. Madden<sup>1</sup> & S. Smith<sup>2</sup>

<sup>1</sup>School of Life and Medical Sciences, University of Hertfordshire, Hatfield, UK

<sup>2</sup>School of Health Sciences, Queen Margaret University, Edinburgh, UK

### Keywords

anthropometry, body composition, height, nutritional status, sagittal diameter, skinfolds, waist circumference, weight.

### Correspondence

A. Madden, School of Life and Medical Sciences, University of Hertfordshire, Hatfield AL10 9AB, UK.

Tel.: +44 (0)1707 281385

E-mail: a.madden@herts.ac.uk

### How to cite this article

Madden A.M. & Smith S. (2014) Body composition and morphological assessment of nutritional status in adults: a review of anthropometric variables. *J Hum Nutr Diet* doi: 10.1111/jhn.12278

### Abstract

Evaluation of body composition is an important part of assessing nutritional status and provides prognostically useful data and an opportunity to monitor the effects of nutrition-related disease progression and nutritional intervention. The aim of this narrative review is to critically evaluate body composition methodology in adults, focusing on anthropometric variables. The variables considered include height, weight, body mass index and alternative indices, trunk measurements (waist and hip circumferences and sagittal abdominal diameter) and limb measurements (mid-upper arm and calf circumferences) and skinfold thickness. The importance of adhering to a defined measurement protocol, checking measurement error and the need to interpret measurements using appropriate population-specific cut-off values to identify health risks were highlighted. Selecting the optimum method for assessing body composition using anthropometry depends on the purpose (i.e. evaluating obesity or undernutrition) and requires practitioners to have a good understanding of both practical and theoretical limitations and to be able to interpret the results wisely.

### Introduction

Technological advances have increased knowledge and understanding of body composition and its influence on health risk and clinical outcome. As a consequence of these advances, new concepts have emerged, such as sarcopenia, dynapenia, obesity paradox and intermuscular adipose tissue. For healthcare practitioners to be able to evaluate body composition correctly, there is a need for a critical understanding of the strengths, limitations and issues for practice, of both current and emerging methods. Furthermore, as healthcare becomes more outcome-driven, it is important that practitioners strive to identify and use valid methods that can not only evaluate baseline nutritional status and effects of nutritional interventions, but also contribute to the development of practice. The aim of this two-part review is to critically evaluate body composition methodology in adults, with part one focus-

ing on anthropometric variables and part two focussing on the use of bioelectrical impedance analysis, markers of muscle strength, functional status and imaging techniques with particular reference to developments relevant to practice.

### Height and weight

#### Height

Height is used in public health and clinical nutrition to assess risk of undernutrition and obesity (Elia, 2003), to estimate basal metabolic rate (Henry, 2005) and to determine drug dose (Pai, 2012). Accurate measurement requires a standardised procedure and the use of appropriate, calibrated measuring equipment. Surveys of nutritional status use standard measurement techniques and, for standing height, require shoes to be removed, with the measured person standing upright with arms loosely

to the side, back straight, heels against a vertical measure and the head in the Frankfort plane (Fig. 1). Height is measured after a deep in-breath, ensuring that the head remains in the correct position (Department of Health, 2012). The careful following of a standardised protocol is recommended to minimise intra-observer technical error of measurement, which may be as high as 1.3 cm for adult height (Ulijaszek & Kerr, 1999).

Height can be measured using a free-standing or portable stadiometer, or a wall-mounted measure. Comparisons of equipment indicate no significant difference in height measured (Voss & Bailey, 1994; Geeta *et al.*, 2009). However, incorrectly assembled or positioned measuring equipment leading to inaccurate measurements have been reported and thus regular calibration is required (Voss *et al.*, 1990; Biehl *et al.*, 2013).

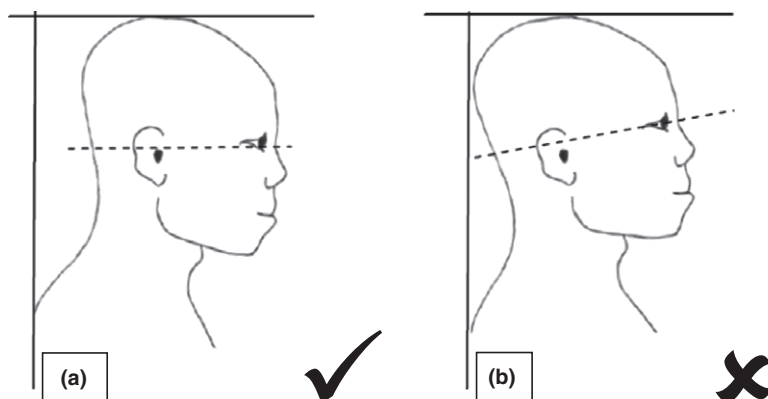
Variation in standing height during the day has been reported in healthy volunteers with afternoon measurements of approximately 6 mm less than those recorded 7 h earlier (Coles *et al.*, 1994). Conversely, resting supine for approximately 50 min is associated with significantly greater height (>5 mm) in women than pre-resting values during osteoporosis screening (Coles *et al.*, 1994). This indicates the need for paying careful attention to a standardised procedure when accurate serial measurements are required (Stothart & McGill, 2000). Longitudinal studies indicate a loss of height with increasing age in adults of approximately 1 mm per year after age 40 years, with an increasing rate of loss with age (Dey *et al.*, 1999; Sorkin *et al.*, 1999).

Factors that may impede accurate measurement of standing height range from minor confounders (e.g. hair braiding) to abnormal spinal curvature (e.g. idiopathic scoliosis, spinal injury, muscular dystrophy and Marfan syndrome), which precludes adherence to the measurement protocol. The prevalence of scoliosis in otherwise healthy adults is estimated at 8–30% but, in older adults, may be approximately 68% (Carter & Haynes, 1987;

Schwab *et al.*, 2005). Corrections to height measurements in scoliosis may be made using stereophotogrammetric ISIS scanning (Carr *et al.*, 1989), although this may not be practical. A method for estimating height in patients with contractures has been proposed recently by Finch & Arumugam (2014) and may comprise a more useful approach. An inability to stand for height measurement has been reported in many elderly people in nursing homes and in hospitalised patients (Berkhout *et al.*, 1989; Elia, 2003). In practice, deciding whether a patient has scoliosis or whether they are able to stand for measurement may be subjective and so practitioners are advised to carefully consider each patient's circumstances and clearly document their observations, as well as how height was derived.

When height cannot be measured, an approximation can be derived from self-reported values and observer estimation or be calculated from other body measurements using prediction equations. A systematic review of studies comparing self-reported and measured height found an overall tendency to overestimate height, with studies reporting mean differences of up to 7.5 cm (Connor Gorber *et al.*, 2007). Loss of height with increasing age is associated with greater inaccuracies of self-reported height, with studies of adults aged  $\geq 65$  years reporting mean overestimates of 2.3–5 cm and a worst individual overestimate of 18.5 cm; greater differences in women were probably associated with greater osteoporosis-related bone loss (Payette *et al.*, 2000; Frid *et al.*, 2013; Reidlinger *et al.*, 2014).

The implications of using self-reported height may depend on what the values are used for. For example, a study of 146 patients with a mean (SD) age of 56 (15) years and body mass index (BMI) of 27.9 (5.7)  $\text{kg m}^{-2}$  found that using self-reported height and weight do not appear to influence malnutrition screening outcome (Stratton *et al.*, 2003a). A study of 15 men and 22 women aged  $\geq 70$  years observed no significant



**Figure 1** Position of head for measuring height using (a) Frankfort plane where lower eye socket is horizontally level with upper ear canal and (b) typical but incorrect position (Madden *et al.*, 2012).

difference in BMI when calculated from self-reported or measured height in men but significantly lower BMI calculated from self-reported height in women (Reidlinger *et al.*, 2014). Further research in a wider population is needed to confirm the usefulness of self-reports. A study comparing measured height with values estimated by healthcare professionals reported that these were less accurate than self-reports with only 41% of estimates within 2.54 cm of measured values (Hendershot *et al.*, 2006). Evidence to date does not support the routine use of self-reported or observer estimated height.

Published equations allow estimated height to be calculated from a range of different body measurements, including knee height (Chumlea & Guo, 1992; Han & Lean, 1996; Ritz, 2004), arm span (Brown *et al.*, 2000; Mohanty *et al.*, 2001; de Lucia *et al.*, 2002; Capderou *et al.*, 2011), demi-span (Bassey, 1986; Hirani & Aresu, 2012), ulna length (Elia, 2003; Auyeung *et al.*, 2009) and hand length (Guerra *et al.*, 2014) (Table 1). The relationship between height and other body variables is influenced by several factors, including age and ethnicity (Steele & Chenier, 1990; Launer & Harris, 1996; Reeves *et al.*, 1996; Chumlea *et al.*, 1998; Mohanty *et al.*, 2001; Madden *et al.*, 2012). For example, arm span is approximately equal to height in White adults but greater than height in Black Africans and Asians (Steele & Chenier, 1990; Reeves *et al.*, 1996). Some published equations have been derived in young and healthy populations and so their use in hospitalised patients has been questioned (Hickson & Frost, 2003). Studies evaluating the accuracy and precision of calculated height have been undertaken in different populations and with varying conclusions (Hickson & Frost, 2003; Shahar & Pooy, 2003; Van Lier *et al.*, 2007; Auyeung *et al.*, 2009; Reidlinger *et al.*, 2014). Overall, these indicate that equations that are derived in a population with age and ethnicity comparable to the people in whom they will be used are most likely to yield accurate estimates of height. At present, it is not possible to make a globally useful recommendation for the best prediction method of predicting height and a systematic review of comparison studies is needed.

When measuring other body dimensions to enable height to be calculated, practicality should also be considered especially because this is often required in bed-bound or frail individuals. As a result, procedures that require little effort from the subject and minimal undressing are more useful. From this perspective, measuring ulna length and knee height may be more practical than arm span or demi-span when an older person is unable to stretch out or hold their arms for measurement. In the absence of clear evidence of superior validity of any single proxy height measure or equation, practitioners are advised to view all estimates of height with caution and

select methodology on the basis of practicality and an equation derived in a comparable population.

## Weight

Body weight represents the sum of all body compartments (i.e. fat-free mass and fat mass) but does not discriminate between these. Therefore, changes in body weight may represent alterations in muscle, fat, water or a combination of these and so, from a nutritional perspective, they provide limited information. Despite this, body weight is routinely measured in healthcare and used to assess health status and future clinical risk.

A standardised weighing technique requires the removal of shoes, outer garments such as jackets and cardigans, heavy jewellery, loose change and keys. Participants then stand with their feet together in the centre of the scales with heels against the back edge with arms hanging loosely by their sides and head facing forward, not down (Department of Health, 2012). The weight recorded includes light clothing. Records from the 1960s indicate this is approximately 0.9 kg, with men tending to wear slightly heavier clothes than women but, currently, this may be lighter (Stevens *et al.*, 2006). Providing that a consistent approach is taken, no allowance should be made for the weight of clothes worn during weighing. Similarly, no allowance is made for diurnal variation, which may be as much as 2 kg as a result of food and fluid intake and bladder and bowel evacuation (Lohman *et al.*, 1988).

Fluctuation in body weight associated with physiological changes in fluid balance in healthy adults may lead to small inaccuracies but is unlikely to mask systematic changes in body weight as a result of a loss or gain of muscle or fat mass. For example, changes in fluid weight measured across the menstrual cycle in 98% of healthy young women were <0.75 kg or 1.2% (Watson & Robinson, 1965), whereas dehydration that is sufficient to invoke thirst is likely to be associated with a weight change of up to 1.5% (Stevens *et al.*, 2006). Body weight fluctuation of 1.1–3.6% over a 3-day period has been reported in well-hydrated patients aged  $\geq 60$  years but variation in weight can be reduced to  $\leq 0.4$  kg if repeat measurement is undertaken at the same time of day (Vivanti *et al.*, 2013).

Pathological changes in fluid balance may be greater and have the potential to obscure nutritionally important changes in other body compartments even when fluid changes are not clinically detectable (Bellizzi *et al.*, 2006; Morgan *et al.*, 2006). In haemodialysis, a mean (SD) interdialytic weight change of 1.9 (1.6) kg has been observed (Chan *et al.*, 2008) but may be higher with gaining  $\geq 4.0$  kg between dialysis associated with adverse

**Table 1** Examples of equations for estimating height from other body measurements in adults

Measured variable	Reference	Equation	Derivation population	Notes of validation and/or limitations
Knee height	Chumlea & Guo (1992)	White male: Height = 59.01 + (2.08 knee height) Black male: Height = 95.79 + (1.37 knee height) White female: Height = 75.0 + (1.91 knee height) – (0.17 age) Black female: Height = 58.72 + (1.96 knee height)	488 men, 513 women 18–80 years 89% White; 11% Black Living at home (National Health Examination Survey) USA	Tested by authors in a separate elderly population. Equations for Black men and women derived from smaller number of participants
	Ritz (2004)	Height = 77.08 + (1.87 knee height) – (0.173 age) + (4.22 gender)	126 elderly adults 81.8 ± 8.3 years Hospital inpatients Six centres in France	Numerical multiplier not published for gender
Lower leg length	Han & Lean (1996)	Male: Height = 51.1 + (2.31 lower leg length) Female: Height = 70.2 + (1.84 lower leg length)	78 men, 82 women 17–82 years Glasgow, UK	Validated by in a separate population
Arm span	Brown <i>et al.</i> (2000)	Height = 20.54 + (0.87 arm span) Height = 40.91 + (0.75 arm span) – (0.05 age) + (4.04 gender)	26 men, 57 women 20–61 years University students and staff 95% White New York, USA	Numerical multiplier for male = 1; female = 0
	Mohanty <i>et al.</i> (2001)	Height = 49.57 + (0.674 arm span)	505 women 20–29 years College students Karnataka, India	
	de Lucia <i>et al.</i> (2002)	Male: Height = 56.8 + (0.67 arm span) Female: Height = 52.1 + (0.68 arm span)	214 men, 215 women 18–50 years Somali adults Ethiopia	Study included three other Ethiopian ethnic groups and height: arm span relationship varied with ethnicity and gender
Demi-span	Capderou <i>et al.</i> (2011)	Male: Height = 54.1 + (0.70 arm span) – (0.08 age) Female: Height = 43.1 + (0.75 arm span) – (0.08 age)	1281 men, 1091 women 20–90 years Patients referred for respirometry 100% White Paris, France	
	Bassey (1986)	Male: Height = 57.8 + (1.40 demi span) Female: Height = 60.1 + (1.35 demi span)	63 men, 62 women 20–45 + years European Nottingham, UK	
Ulna length	Hirani & Aresu (2012)	Male: Height = 73.0 + (1.30 demi span) – (0.10 age) Female: H = 85.7 + (1.12 demi span) – (0.15 age)	1174 men, 1295 women ≥65 years Living at home (Health Survey for England) 98% White England, UK	Equations derived in large, nationally representative sample. Small proportion of non-White participants might limit application to all ethnic groups. Recently published so no external validation yet
	Elia (2003)	Male <65 years: Height = 79.2 + (3.60 ulna length) Male ≥65 years: Height = 86.3 + (3.15 ulna length) Female <65 years: Height = 95.6 + (2.77 ulna length) Female ≥65 years: Height = 80.4 + (3.25 ulna length)	117 men, 107 women <65 years 112 men, 98 women ≥65 years	Details of derivation population not available. Equations widely used in national screening. Accuracy in non-White population, especially Asian women, questioned (Madden <i>et al.</i> 2012)

**Table 1** (Continued)

Measured variable	Reference	Equation	Derivation population	Notes of validation and/or limitations
Ulna & fibula length	Auyeung <i>et al.</i> (2009)	Male: Height = 74.7 + (2.235 fibula length) + (0.519 ulna length) – (0.0656 age) Female: Height = 85.9 + (1.137 fibula length) + (1.739 ulna length) – (0.167 age)	2443 adults 65–98 years Living at home 100% Chinese Hong Kong	Accuracy and precision of predictions are comparable with those from knee height
Hand length	Guerra <i>et al.</i> (2014)	Male: Height = 80.400 + (5.122 hand length) – (0.195 age) + 6.383 Female: Height = 80.400 + (5.122 hand length) – (0.195 age)	173 men; 138 women 19–91 years Hospital patients Caucasians Portugal	Equations validated against a separate group of patients from the same study population with mean difference (95% confidence interval) of 0.6 (–1.7, 0.4) cm

All lengths measured in cm; age measured in years.

clinical outcome (Hecking *et al.*, 2013). In liver disease, large-volume paracentesis may be accompanied by a mean weight loss of 13.8 (0.5) kg over 72 h (Van Thiel *et al.*, 2011), whereas creeping fluid accumulation may obscure simultaneous loss of muscle. Estimates of excess fluid weight in patients with alcoholic liver disease have been made by considering weight gained during re-feeding (Table 2) (Mendenhall, 1992). Estimates of weight associated with oedema have been used for some decades and are included in practice guidance (Table 2) (Todorovic *et al.*, 2011), although the evidence underpinning these is unknown. Our own clinical experience indicates that weight gain associated with ascites and oedema varies considerably and, in extreme cases, this may be >25 kg. Estimates of fluid weight can be informed through discussion with clinical colleagues, considering results from abdominal ultrasound scanning and careful evaluation of serial weight measurements. Even so, estimates of fluid weight must be made cautiously, recorded clearly and their limitations recognised.

Adjustment to measured body weight may also be required following limb amputation (Table 3) and more detailed discussion is provided by Osterkamp (1995). Measured body weight may also require adjustment when

**Table 2** Estimated contribution of fluid to body weight in patients with alcoholic hepatitis and ascites (Mendenhall, 1992) and with oedema (Todorovic *et al.*, 2011)

Clinical description of:	Estimated fluid weight (kg)
Ascites	
Minimal	2.2
Moderate	6
Tense	14
Oedema	
Barely detectable	2
Severe	>10

an unmoveable cast is worn and estimates are available (Table 3). However, variation in cast material and structure may influence its weight by approximately 40% and so discussion with plaster-room staff is helpful when a more accurate value is required (Charles & Yen, 2000; Stewart *et al.*, 2009).

Body weight is measured using step-on, seat or bed scales, which operate using either a digital or balance mechanism. Standardised procedures should be applied; for example, for bed scales, remove most of the bedding except the bottom sheet and one pillow, and do not weight urinary catheter bag, etc. The type of scale used may influence measured values by up to 1.6 kg, with greater discrepancy associated with heavier weight (Byrd *et al.*, 2011). Many scales that are available in clinical and primary care settings are capable of weighing up to 150–200 kg, which is less than some obese adults. These will require a bariatric platform to enable weight monitoring

**Table 3** Adjustment of body weight following amputation or with an immovable cast (BAPEN, 2012)

Amputation	Contribution to total body weight (%)	Multiplier of measured weight required for adjustment
Upper limb	4.9	1.05
Upper arm	2.7	1.03
Fore arm	1.6	1.02
Hand	0.6	1.01
Lower limb	15.6	1.18
Thigh	9.7	1.11
Lower leg	4.5	1.05
Foot	1.4	1.01
Cast		Estimated weight of cast
Upper limb cast		<1 kg
Lower leg or back cast		0.9–4.5 kg



and these, with hand rails for stability, can weigh individuals up to 500 kg. Regular calibration is required to ensure that reliable values are obtained and this is a legal requirement for scales in the UK (UK Statutory Instrument, 2000). The maximum error permitted is determined by the class of scale and its divisions. For example, weighing a 70 kg man on a class III scale (i.e. suitable for medical establishments) with 100 g divisions requires accuracy of two divisions (i.e.  $\pm 200$  g), whereas, weighing a 200 kg person on the same scale requires accuracy within three divisions (i.e.  $\pm 300$  g).

When weighing is not possible, self-reported weight can be used, although systematic review indicates a wide variation in reports with a tendency for weight to be underestimated and mean differences between estimated and measured values of up to 6.5 kg (Connor Gorber *et al.*, 2007). A study comparing measured and self-reported weight in hospitalised patients aged  $\geq 16$  years with values estimated by healthcare professionals found that the estimates of healthcare professionals were less accurate than self-reports, with only 53% of estimates within 10% of measured values and with greater errors, predominantly underestimates, made in obese individuals (Hendershot *et al.*, 2006). Evidence published to date does not support the routine use of self-reported or observer-estimated weight.

Both height and weight are routinely measured in public health and clinical nutrition but are not necessarily considered measurements requiring high skill or precision. However, as described, both have potential for inaccurate measurement and these may lead to cumulative errors with the potential to impact on diagnostic categorisation with important implications for clinical practice. For example, a small 1-cm error in height will result in approximately  $0.3 \text{ kg m}^{-2}$  difference in body mass index, whereas a 0.5-kg error in weight will result in  $0.2 \text{ kg m}^{-2}$  difference. However, when combined, these errors could lead to values of body mass index differing by up to  $0.9 \text{ kg m}^{-2}$  with greater discrepancy observed in shorter individuals. Further examples of the impact of errors on body mass index are described in Madden *et al.* (2012) and Guerra *et al.* (2014).

### Body mass index and alternative indices

Body mass index describes the relationship between body weight and stature (Quetelet, 1869; Keys *et al.*, 1972):

$$\text{BMI} = \frac{\text{weight (kg)}}{\text{height squared (m}^2\text{)}}$$

It is widely used in public health and clinical nutrition to provide a quick evaluation of nutritional wellbeing; for example, in assessing obesity or malnutrition risk

(BAPEN, 2012; World Health Organisation, 2014). Increasing BMI is associated with increased risk of mortality, cardiovascular disease and some cancers (Renehan *et al.*, 2008; Huxley *et al.*, 2010; Flegal *et al.*, 2013), whereas a lower BMI is associated with an increased risk of mortality, post-surgical complications, infection and length of hospital stay (van Venrooij *et al.*, 2008; Falagas *et al.*, 2009; Cereda *et al.*, 2011; Gupta *et al.*, 2011). As a result, BMI is included in several widely-used nutritional screening tools (Elia, 2003; Skipper *et al.*, 2012).

The World Health Organization classification of BMI describes eleven principal categories ranging from severe thinness to obesity class III (Table 4). The cut-offs for these categories are based on health risk associated with both under- and over-nutrition but, because they are intended for global use, additional cut-offs allow for regional variation (World Health Organization, 2014). For example, the risk of diabetes and cardiovascular disease is associated with lower BMI values in Asians compared to other groups.

However, because BMI is derived from body weight, which does not discriminate between muscle and fat mass, BMI is also unable to differentiate between individuals with high values as a result of greater muscle and those with more adipose tissue. This is clearly a limitation, particularly in taller individuals and well-muscled athletic men (Deurenberg *et al.*, 1999; Larsson *et al.*, 2006). In addition, because BMI considers the body as a whole rather than regionally, it is unable to identify where body fat is located. This is important because of the increased health risks associated with visceral fat in

**Table 4** The international classification of adult underweight, overweight and obesity according to body mass index (World Health Organization, 2014)

Classification	Body mass index ( $\text{kg m}^{-2}$ )	
	Principal cut-off points	Additional cut-off points
Underweight	<18.50	<18.50
Severe thinness	<16.00	<16.00
Moderate thinness	16.00–16.99	16.00–16.99
Mild thinness	17.00–18.49	17.00–18.49
Normal range	18.50–24.99	18.50–22.99 23.00–24.99
Overweight	$\geq 25.00$	$\geq 25.00$
Pre-obese	25.00–29.99	25.00–27.49 27.50–29.99
Obese	$\geq 30.00$	$\geq 30.00$
Obese class I	30.00–34.99	30.00–32.49 32.50–34.99
Obese class II	35.00–39.99	35.00–37.49 37.50–39.99
Obese class III	$\geq 40.00$	$\geq 40.00$

the abdomen rather than peripheral fat (Kuk *et al.*, 2006). This has led to the TOFI concept ('thin-on-the-outside, fat-on-the-inside') which describes lean people with increased abdominal adiposity associated with metabolic risk (Thomas *et al.*, 2012).

In an attempt to address BMI limitations but still consider the whole body, alternative indices have been developed based on different mathematical combinations of body measurements (Table 5). For an alternative index to be useful either in clinical practice or public health, a strong predictive relationship with clinical outcome is required and it is likely that this will vary with outcomes and in different populations. The practicality of undertaking the measurements required for some indices should also be considered because some, for example, fat mass, which is required for the fat-mass index (Schutz *et al.*, 2002), may be difficult to assess accurately outside research facilities. Complex computation (e.g. raising values to a fractional power), such as in the body adiposity index and body shape index (Bergman *et al.*, 2011; Krakauer & Krakauer, 2012), will require a functional

calculator, potentially discouraging clinical use. In addition, poor agreement in categorising health risk by different indices of adiposity indicates at an individual level raises concern over the interpretation in practice (Meredith & Madden, 2014).

Meta-analysis of studies evaluating different indices of adiposity indicates that waist to height ratio (WHtR), which is discussed below, is a better predictor of diabetes, hypertension, dyslipidaemia, metabolic syndrome and other cardiovascular outcome measures than BMI or waist circumference in both men and women (Ashwell *et al.*, 2012). A WHtR cut-off of <0.5 is recommended, which can be presented as a simple public health message to keep waist circumference less than half height. Although BMI has limitations, it is important not to dismiss it because it does predict mortality and morbidity (although less strong than WHtR, Taylor *et al.*, 2010; Ashwell *et al.*, 2012), is widely used and understood in both clinical and public health contexts, and provides an evaluation of malnutrition risk as well as obesity.

**Table 5** Examples of alternative indices for assessing adiposity

Index	Reference	Calculation	Cut-off values*	Comments
A body shape index (ABSI)	Krakauer & Krakauer (2012)	= Waist circumference/ (BMI <sup>2/3</sup> height <sup>1/2</sup> )	Top 40%	Associated with premature mortality in USA population.
Body adiposity index	Bergman <i>et al.</i> (2011)	= (Hip circumference/ height <sup>1.5</sup> ) - 18	Data not presented	Does not require weight measurements; associated with % body fat in African-Americans; association with cardiovascular risk less than BMI (Snijder <i>et al.</i> , 2012)
Demiquet	Lehmann <i>et al.</i> (1991)	= weight/demispan <sup>2</sup>	NA; see reference for age-specific percentiles	Used in men, more commonly when height unavailable, e.g. in elderly (see mindex)
Fat-mass index	Schutz <i>et al.</i> (2002)	= fat mass/height <sup>2</sup>	Male >8.2 kg m <sup>-2</sup> Female >11.8 kg m <sup>-2</sup>	Requires values of fat or fat-free mass; proposed amendment using height <sup>3</sup> in place of height <sup>2</sup> (Burton, 2010)
Mindex	Lehmann <i>et al.</i> (1991)	= weight/demispan	NA; see reference for age-specific percentiles	Used in women, more commonly when height unavailable, e.g. in elderly (see demiquet)
Ponderal index	Cole <i>et al.</i> (1997)	= weight/height <sup>3</sup>	NA for adults	More commonly used in infants
Waist to height ratio	Ashwell <i>et al.</i> (1996)	= Waist circumference/ height (same units)	Male & female >0.50	Meta-analysis indicates good predictor of metabolic risk in different populations (Ashwell <i>et al.</i> 2012)
Waist to hip ratio	Lanska <i>et al.</i> (1985), World Health Organization (2008)	= Waist circumference/hip circumference (same units)	Male ≥0.90 Female ≥0.85	Predictor of all-cause mortality, especially in BMI >22.5 kg/m <sup>2</sup> (Taylor <i>et al.</i> 2010)

Abbreviations and units (except where indicated in table): BMI, body mass index (kg m<sup>-2</sup>); demispan (cm); fat mass (kg); hip circumference (cm); height (m); NA, not available; waist circumference (m); weight (kg).

\*Cut-off values commonly used to identify excess fat ± risk associated with obesity. Note that these vary with population and specific health risks.

## Trunk circumferences and diameter

Measurement of body trunk is useful for assessing health risk associated with obesity but not undernutrition.

### Waist circumference

Waist circumference provides an indicator of central adiposity that is usually easily obtained. It is a good predictor of cardiometabolic morbidity and mortality (Taylor *et al.*, 2010; Ashwell *et al.*, 2012) and, although it is less strongly predictive than WHtR, its value lies in the requirement for a single measurement taken with just a simple nonstretch tape. Accurate measurement requires a standardised procedure. A standardised technique requires the person being measured to remove bulky outer or tight garments and shoes with heels, empty their bladder then stand upright with arms loosely to the side. The tape is passed round the body and positioned mid-way between the iliac crest and costal margin of the lower rib, ensuring it is horizontal and untwisted. The subject is asked to look ahead and breathe out and the measurement is taken at the end of expiration and the procedure repeated (Department of Health, 2012). Different anatomical sites have been described for measuring waist circumference, including the minimum abdominal circumference and at the level of the umbilicus. These yield significantly different values (Wang *et al.*, 2003), which will impair serial measurements in clinical practice and so practitioners are advised to record the site measured. However, the variation observed does not appear to influence risk prediction (Ross *et al.*, 2008). Even when a standardised technique is used, measurement variability increases with adiposity in women (coefficient of variation 0.050 in those  $\leq 50$  kg and 0.091  $\geq 88$  kg, Sonnenschein *et al.*, 1993).

Measurements of waist circumference cannot be made or are not reliable in people who are unable to stand, are pregnant or have a colostomy, ileostomy or ascites, and do not provide useful information in lean or underweight individuals. The International Diabetes Federation published a series of waist circumference cut-off values that are country/ethnic group specific and can be used to assess diabetes risk (Alberti *et al.*, 2007) (Table 6) and these are included in UK public health guidance (NICE, 2013). The cut-offs are not age-specific, which is a limitation because waist circumference typically increases in both men and women with age. For example, in the USA National Health and Nutrition Examination Survey (NHANES) III, median waist circumference in men and women aged 20–29 years was 85.8 and 76.6 cm, respectively, compared to 101.9 and 94.0 cm in those aged 60–69 years (Ford *et al.*, 2003).

**Table 6** Cut-off points for use in different countries/ethnic groups to identify health risk associated with central obesity; measurements above these values are associated with an increased risk.

Country/ethnic group	Waist circumference (cm) (Alberti <i>et al.</i> , 2007)
Europids	
Male	$\geq 94$
Female	$\geq 80$
South Asians	
Male	$\geq 90$
Female	$\geq 80$
Chinese	
Male	$\geq 90$
Female	$\geq 80$
Japanese	
Male	$\geq 90$
Female	$\geq 80$
Ethnic South and Central American	Use South Asian recommendation until more specific data are available
Sub-Saharan African	Use European data until more specific data are available
Eastern Mediterranean and Middle East (Arab) populations	Use European data until more specific data are available
Sagittal abdominal depth (cm).	
Brazil (Duarte Pimentel <i>et al.</i> 2010)	
Male	$\geq 23.1$
Female	$\geq 20.1$
Sweden (Risérus <i>et al.</i> 2010)	
Male	$\geq 22.0$
Female	$\geq 20.0$
UK* (Valsamakis <i>et al.</i> 2004)	
Male	$\geq 27.6$

\*Includes White and Indo-Asian participants.

### Hip circumference

Hip circumference also provides an indication of adiposity although its value in predicting health risk is unclear for all-cause mortality (Taylor *et al.*, 2010). Meta-analysis of 18 studies indicates a significant and inverse relationship between hip circumference and type 2 diabetes risk [men: relative risk = 0.60 (95% confidence interval = 0.45–0.80)  $P = 0.003$ ; women relative risk = 0.57 (0.48–0.68)  $P = 0.005$ ; Janghorbani *et al.*, 2012]. This protective effect appears stronger in study populations in the USA and Asia than those from Europe. The possible mechanism for protection may be associated with either muscle or adipose stores. A standardised procedure for measuring hip circumference requires the person to be prepared as for measuring waist circumference (above). The tape should be passed round them and positioned at the widest part over the buttocks and below the iliac crest, ensuring it is horizontal and untwisted. The subject is asked not to



contract their gluteal muscles before the measurement is taken and then the procedure is repeated (Department of Health, 2012). Measurement of hip circumference is straightforward and associated with low technical error of measurement [mean intra-observer 0.013 m (range 0.013–0.014) and mean inter-observer 0.028 m (0.007–0.061); Ulijaszek & Kerr, 1999]. The measurement variability of hip circumference with increasing adiposity in women is less than values reported for waist circumference (CV 0.025 in those  $\leq 50$  kg;  $0.072 \geq 88$  kg; Sonnenschein *et al.*, 1993).

The interpretation of hip circumference is usually based on waist-hip ratio (WHR) rather than comparison against cut-off values. Early reports of the health effects of central adiposity based on WHR included increased risk of diabetes in women (Hartz *et al.*, 1983) and cardiovascular disease in men (Larsson *et al.*, 1984). Subsequently, WHR has become accepted as a useful predictor of health risk comparable with BMI and waist circumference alone, with small variation depending on the clinical end point (e.g. diabetes, hypertension, dyslipidaemia or cardiovascular mortality) (World Health Organization, 2008; Huxley *et al.*, 2010). Globally, WHR values  $\geq 0.90$  in men and  $\geq 0.80$  in women are associated with substantially increased risk of metabolic complications but, similar to waist circumference, different cut-off values are recommended for different populations as a result of variations in visceral adiposity for a given waist circumference with ethnicity (World Health Organization, 2008).

### Sagittal abdominal diameter

Sagittal abdominal diameter (SAD) is a measure of the anterior–posterior thickness of the abdomen and can be measured using a portable sliding beam abdominal caliper. The caliper is applied at the L4–L5 region of the abdomen, midway between the iliac crest and the lowest palpable rib and measurement is taken at the end of normal expiration when standing upright (Gletsu-Miller *et al.*, 2013) or lying supine (i.e. supine abdominal height) (Risérus *et al.*, 2010). The former may address practical difficulties in measuring waist circumference in individuals with a large abdomen and the latter may afford opportunities for use in non-ambulatory individuals. However, differences in subject position may produce differences in results and therefore protocol standardisation is required for serial measurements.

Sagittal abdominal diameter has been proposed as a better marker of abdominal visceral adiposity than waist circumference with validation studies comparing SAD to imaging techniques demonstrating correlation coefficients between 0.724 and 0.804 (Kullberg *et al.*, 2007; Yim *et al.*, 2010). Studies undertaken in populations differing in ethnicity, age and BMI have identified SAD as a better

predictor of cardiovascular, metabolic risk (Valsamakis *et al.*, 2004; Kullberg *et al.*, 2007; Risérus *et al.*, 2010; Yim *et al.*, 2010; Gletsu-Miller *et al.*, 2013; Anunciação *et al.*, 2014), although this has not yet been evaluated by systematic review. Cut-off values for predicting elevated cardiovascular risk have been proposed (Table 6) and further work is required to establish prognostically useful values in more diverse populations.

### Limb circumferences

Measurement of limb circumference is used to evaluate risk of malnutrition rather than obesity and, although typically undertaken on the mid-upper arm, measurements of lower limbs also provide useful data.

#### Mid-upper arm circumference

Mid-upper arm circumference (MUAC) is used to identify chronic energy deficiency (James *et al.*, 1994) and as a predictor of mortality in acutely hospitalised adults (Powell-Tuck & Hennessy, 2003) and can also be used to predict BMI when height or weight are unavailable:

$$\text{Male: BMI(kg/m}^2\text{)} = 1.01 \times \text{MUAC(cm)} - 4.7$$

$$\text{Female: BMI(kg/m}^2\text{)} = 1.10 \times \text{MUAC(cm)} - 6.7$$

From these equations, MUAC  $<25$  and  $<23.5$  cm approximately equates to BMI  $<20$  and  $<18.5$  kg m<sup>-2</sup>, respectively, and raises potential concern about nutritional status indicating the need for more detailed assessment. Analysis of comparable USA data indicates that MUAC of  $<24.7$  cm in men and  $<23.5$  cm in women corresponds to a BMI of  $<18.5$  kg m<sup>-2</sup> (Flegal & Graubard, 2009). Additional international data is provided in World Health Organization (1995). If BMI is derived from MUAC, the results should be interpreted with caution because although mean differences may be small ( $<0.1$  kg m<sup>-2</sup>), 95% confidence intervals of the differences range between  $-5.6$  and  $+4.1$  kg m<sup>-2</sup> (Houghton & Smith, 2011). Studies investigating the prognostic role of MUAC have yielded differing conclusions, possibly because of different study populations (Burden *et al.*, 2005; de Hollander *et al.*, 2013). Measurements of MUAC are therefore useful in nutritional screening when used as a sole measurement (BAPEN, 2012) and in nutritional assessment or body composition analysis when used with triceps skinfold (TSF) to calculate mid-arm muscle circumference or area (see below).

### Leg circumferences

Most skeletal muscle in adults is distributed in the lower rather than upper limbs (Rolland *et al.*, 2003). Depletion

in muscle mass associated with nutritional change is not uniform across the body with relative preservation of upper limb muscle compared to lower limbs in diabetes (Park *et al.*, 2007) and with increasing age (Janssen *et al.*, 2000). Therefore, anthropometric measurement of the lower limbs has the potential to be a good predictor of whole body muscle mass (Rolland *et al.*, 2003; Smith *et al.*, 2005) and could be particularly useful in assessing and monitoring in older adults or those with long-term conditions (e.g. chronic kidney disease, cardiovascular disease or diabetes).

Although thigh muscle volume determined by magnetic resonance imaging correlates strongly with physical function in older people (Chen *et al.*, 2011), the practicalities of obtaining this measurement are likely to limit its use in clinical practice. Consequently, lower limb studies have focused on the measurement of calf circumference. This combines a quantitative assessment of lower limb mass with functional ability, physical-related quality of life and frailty (Allen *et al.*, 2002; Landi *et al.*, 2014) and, when corrected for fat mass, is associated with risk of falling (Stewart *et al.*, 2002).

Calf circumference is simple to measure and requires only the use of a tape measure to obtain a maximal circumference without indentation of the skin. The measurement of calf circumference has similar intra- and inter-observer error to MUAC and significantly less error than measurements of TSF (Ulijaszek & Kerr, 1999). It can be measured on the right or left leg and when seated (Stewart *et al.*, 2002; Landi *et al.*, 2014) or in a supine position, thereby increasing its usefulness (Rolland *et al.*, 2003). Standardisation of protocols is required to reduce variation in results within a population or for longitudinal monitoring (Carin-Levy *et al.*, 2008).

Calf circumference reference values are available from NHANES data derived from 8436 healthy USA adults aged  $\geq 20$ –80 years (McDowell *et al.*, 2008) and from 874 free-living Irish adults aged  $> 65$  years (Corish & Kennedy, 2003). A cut-off  $< 31$  cm has been proposed as an indicator of functional impairment risk (Rolland *et al.*, 2003).

One obvious limitation of calf circumference measurement is the possible confounding effect of peripheral oedema, which is prevalent in approximately 25% of older people (Dunn *et al.*, 2004). Few studies have explored this and it is an area for future research. In addition, as the majority of published studies have focused primarily on older people, evaluation of calf circumference measurement in both younger and diverse populations is required.

### Skinfold anthropometry

Measurement of subcutaneous fat using skinfold calipers allows body fat to be estimated and, by calculation, evalu-

ation of muscle stores. Because intra-abdominal adipose tissue cannot be assessed by skinfold measurement, this technique is more useful in lean individuals (i.e. those with smaller fat stores) than in overweight individuals. The procedure is quick, requires noncomplex portable equipment and thus can be undertaken in most public health and clinical nutrition settings. A variety of calipers are available ranging from precision engineered (e.g. Harpenden, Holtain or Lange) to plastic (e.g. Slimguide). However, measurements may differ between caliper type and plastic ones can be less accurate but may be an option for serial measurements or where disposable equipment is required (Burgert & Anderson, 1979; Schmidt & Carter, 1990).

In addition to the inability to assess intra-abdominal fat and the impact of different patterns of fat distribution, other limitations of skinfold anthropometry include constancy of fat compressibility and skin thickness and the variability of measurements when undertaken by assessors with limited training and experience. However, using standardised techniques, practice and monitoring improves reliability of measurements allowing skinfold anthropometry to provide useful data when more complex methods of assessment are not available or inappropriate. It is recommended that a practitioner using anthropometry skilfully should aim for an intra-observer technical error measurement of  $\leq 5\%$ , whereas  $\leq 7.5\%$  is considered acceptable for an inexperienced practitioner (Perini *et al.*, 2005).

The techniques and specific anatomical positions for measurements are described authoritatively in a number of text books (Lohman *et al.*, 1988; Frisancho, 2008; Stewart & Sutton, 2012) and also in the open access NHANES manual which includes clear photographs (Centers for Disease Control & Prevention, 2005). A number of different equations have been developed to calculate total body fat from skinfolds and the most commonly used are those requiring measurement at four sites (triceps, biceps, subscapular and suprailiac; Durnin & Womersley, 1974) and seven sites (triceps, subscapular, suprailiac, mid-axillary, chest, abdomen and thigh; Jackson & Pollock, 1978; Jackson *et al.*, 1980).

Triceps skinfold is most often used in nutritional assessment (Gray & Gray, 1979). In patients who are unable to stand or sit, TSF can be measured in the supine position and values do not differ significantly from those made when upright (Jensen *et al.*, 1981). Findings from studies that have investigated the independent prognostic value of TSF are not consistent (Harvey *et al.*, 1981; Leandro-Merhi *et al.*, 2011; Valente de Silva *et al.*, 2012; Almeida *et al.*, 2013), although this variation may relate to different study populations, to the adverse effects of high fat stores in some patients and to gender differences

with fat depletion being of greater concern in men who typically, in health, have a smaller percentage of body fat than women. In addition, no studies have investigated whether risk is associated with low fat stores *per se*, or by depletion of fat stores during illness. As a result, TSF measurements can be interpreted by comparison against population standards or, preferably, by using serial measurements to assess change.

Population standards provide a useful overview of the variation in TSF but their application to people with disease has been questioned (Thuluvath & Triger, 1995). In addition, their value may be compromised when increasing levels of obesity at population level lead to changes in cut-off values that might be used for identifying low fat stores (e.g. <5th percentile) (Gray & Gray, 1979; Gassull *et al.*, 1984). The 5th percentile for TSF in the USA published 27 years apart has increased from 4.5 mm in men aged 18–74 years to 6.1 mm in men aged  $\geq 20$  years (Bishop *et al.*, 1981; McDowell *et al.*, 2008). In the absence of evidence that health risk from low TSF changes with increases in fat stores at population level, it is reasonable for continuity to continue to use the earlier standards (Bishop *et al.*, 1981), which allows comparison of data over time providing that the associated limitations are recognised (Thuluvath & Triger, 1995). Serial measurement of TSF allows change in body fat stores to be estimated and so is more useful than comparison with reference values for ongoing monitoring. In addition, TSF is required to calculate mid-upper arm muscle circumference or area.

#### Muscle circumference and muscle area assessed by anthropometry

Mid-arm muscle circumference (MAMC), or specifically mid-upper arm muscle circumference, can be used to evaluate fat-free mass or lean components of the body in nutritional assessment (Gassull *et al.*, 1984) and is also viewed as an outcome measure to evaluate nutritional interventions (Baldwin & Weekes, 2011). It cannot be measured directly by anthropometry but is calculated from MUAC and TSF (Frisancho, 1974):

$$\text{MAMC}(\text{cm}) = \text{MUAC}(\text{cm}) - [\text{TSF}(\text{mm}) \times 0.3142]$$

The prognostic value of MAMC has been described in different clinical and public health settings and lower values are associated with adverse outcome including increased risk of mortality in critical illness (Sungurtekin *et al.*, 2008), haemodialysis (Huang *et al.*, 2010), HIV and tuberculosis infection (Villamor *et al.*, 2006) and in people aged  $\geq 80$  years (Landi *et al.*, 2010). Alternatively, mid-arm muscle area (MAMA) can be used to evaluate fat-free mass and, similar to MUAC,

is calculated from MAMC and TSF (Gurney & Jelliffe, 1973):

$$\text{MAMA}(\text{cm}^2) = \frac{(\text{MUAC}(\text{cm}) - [\text{TSF}(\text{mm}) \times 0.3142])^2}{12.57}$$

Revised equations were proposed by Heymsfield *et al.* (1982) to address the original but incorrect assumptions that the mid-arm and mid-arm muscle are circular, TSF is twice the rim diameter of fat and to take account of the area occupied by bone:

$$\text{corrected MAMA}(\text{cm}^2) = \frac{(\text{MUAC}(\text{cm}) - [\text{TSF}(\text{mm}) \times 0.3142])^2}{12.57} - k$$

where  $k$  equals 10 in men and 6.5 in women. Corrected MAMA correlates with measurements made using computed axial tomography in lean adults but are less accurate with increasing adiposity (Forbes *et al.*, 1988). Both MAMA and corrected MAMA are associated with clinical risk, including a prediction of the length of hospital stay in surgical patients (Almeida *et al.*, 2013) and an increased risk of mortality in the elderly and those with chronic obstructive pulmonary disease (Miller *et al.*, 2002; Soler-Cataluña *et al.*, 2005; Enoki *et al.*, 2007). Although MAMA has been described as preferable to MAMC on the basis of correlation with creatinine/height index (Trowbridge *et al.*, 1982; Gibson, 2005), the advantages are small and there is little evidence that it is a better predictor of body composition or health risk in adults (Scalfi *et al.*, 2002; Vulcano *et al.*, 2013). Therefore, because MAMC is marginally easier to calculate, it is reasonable to use this in nutritional assessment.

Interpreting MAMC or MAMA requires either comparison with population standards or changes associated with serial measures. As discussed above in relation to TSF, population standards are limited in both availability and relevance. No international values are available (World Health Organization, 1995; de Onis & Habicht, 1996) and so values derived from USA populations are most commonly used, although other smaller datasets are available and may be more appropriate for specific European populations (Burr & Phillips, 1984; Bannerman *et al.*, 1997; Corish & Kennedy, 2003). Reference values for MAMC from 20 749 USA adults aged 18–74 years collected in the Health and Nutrition Examination Survey (HANES) between 1971–1974 and presented as 5–95th percentiles are frequently used (Bishop *et al.*, 1981). More recent USA data from 7561 USA adults aged  $\geq 50$  years collected in the NHANES III between 1988–1994 are presented as 10–90th percentiles (Kuczmarski *et al.*, 2000). Data from the most recent NHANES (2003–06) have not been published as MAMC (McDowell *et al.*, 2008). It is not

possible to directly compare the data presented by Bishop *et al.* (1981) and Kuczmarski *et al.* (2000) because the age bands are different (Table 7). However, it is clear in both datasets that MAMC reduces with age in men but not in women and that more recent data are greater, notwithstanding the difference in age banding, than the earlier values suggesting population change. Corrected MAMA reference values from 31 311 persons aged 2 months to 90 years collected in NHANES III (1988–94) are also available and expressed as 5–95th percentiles (Frisancho, 2008).

This presents a potential conundrum about which reference values are most useful for identifying possible under-nutrition, especially in the absence of population- and ethnic-specific datasets. Values <5th percentile have been recommended as evidence of depletion (Gray & Gray, 1979), although other studies have used <15th percentile of MAMC to indicate mild malnutrition and <5th to indicate severe (McWhirter & Pennington, 1994; Corish *et al.*, 2000). It is important to understand the limitations of comparing a single anthropometric value with reference data when assessing nutritional status because differences in measurement proficiency, technique (left/right arm) and ethnicity will impact on the measurement obtained. A value <5th percentile in one set of references but not another is still likely to be borderline low and should trigger concern and further action. Serial measurements taken at least 7 days apart and by an observer who has explored their own ability to measure repeated values to within 5% difference will enable evaluation of change in fat or muscle stores. Changes that are detected in mea-

surements taken at shorter intervals are likely to reflect fluid changes (Green *et al.*, 1995; Reid *et al.*, 2004).

There is no consensus about which side of the body should be measured and published studies report data from right, left and both sides, nondominant arm and unspecified (Stratton *et al.*, 2003b; Gibson, 2005). In national surveys, the right arm is specified in both USA and UK, although the latter does not currently measure skinfolds or MUAC (Centers for Disease Control & Prevention, 2005; Department of Health, 2012). In clinical practice in the UK, the left arm is specified for upper arm anthropometry (Todorovic *et al.*, 2011). Asymmetry has been reported but systematic comparison of anthropometric variables measured on both sides in adults is limited, with comparative studies reporting findings that differ with arm dominance, physical activity and variable being measured (Schell *et al.*, 1985; Krishan, 2011). With regard to skinfolds, the difference between median measurements made at triceps, biceps, subscapular and suprailiac sites on both sides of the body in 164 children aged 7–9 years varied by <0.4 mm (i.e. within the technical error of the procedure) and were not significantly different except at the subscapular where values on the right were lower (Moreno *et al.*, 2002). Skinfolds at the same four sites in 967 male agricultural workers were not significantly different, except at the subscapular where mean values on the right were 0.4–0.6 mm greater depending on age (Krishan, 2011). Although caution is needed in extrapolating these limited and contradictory findings to wider groups, they suggest that differences in TSF are small and so for this measurement, the side of the body is unimportant.

For arm circumferences, significantly greater values have been reported on the right side in children aged 7–9 years and in male agricultural workers and on the dominant arm of healthy women aged ≥40 years (Schell *et al.*, 1985; Krishan, 2011; Dylke *et al.*, 2012). Different measurement techniques were used in these three studies and, although all reported small mean differences (0.17–0.46 cm), individual differences were large and could lead to people being nutritionally assessed differently. In view of this limited evidence, serial MUAC measurements should be taken from the same side of the body, the side should be recorded with the findings and, as discussed above, any comparison against reference data must be interpreted with caution.

## Conclusions

Assessment of nutritional status using anthropometry can be undertaken using a range of methods which vary in their practicality, validity and ability to identify under-nutrition and obesity. The optimum method of choice depends on the subject, the setting and the measurer's

**Table 7** Comparison of selected mid-arm muscle circumference percentiles from USA adults aged ≥50 years collected in 1971–74 (Bishop *et al.*, 1981) and 1988–94 (Kuczmarski *et al.*, 2000).

Data collected	Age range (years)	Sample size	Percentiles (cm)		
			10th	50th	90th
<b>Male</b>					
1971–74	45–54	765	24.9	28.1	31.5
	55–64	598	24.4	27.9	31.0
	65–74	1657	23.7	26.9	29.9
1988–94	50–59	811	25.6	29.2	33.0
	60–69	1119	24.9	28.4	31.4
	70–79	824	24.4	27.2	30.5
<b>Female</b>					
1971–74	45–54	836	19.5	22.2	26.6
	55–64	669	19.5	22.6	26.3
	65–74	1822	19.5	22.5	26.5
1988–94	50–59	927	20.4	23.3	27.8
	60–69	1090	20.6	23.5	27.4
	70–79	898	20.3	23.0	27.0



ability to undertake reliable measurements and interpret them appropriately. The challenges associated with anthropometric assessment can be managed by accurately following standardised protocols and understanding the value and limitations of reference data. Further research to delineate more population-specific cut-off values and explore emerging measurement variables will enhance the role of anthropometry in identifying and monitoring nutritional risk and, importantly, facilitating the evaluation of nutritional interventions.

### Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.

No funding is declared.

SS conceived the original idea and co-wrote the manuscript. AM co-wrote the manuscript. All authors critically reviewed the manuscript and approved the final version submitted for publication.

### References

- Alberti, K.G.M.M., Zimmet, P. & Shaw, J. (2007) International Diabetes Federation: a consensus on type 2 diabetes prevention. *Diabet. Med.* **24**, 451–463.
- Allen, K.L., Miskulin, D., Yan, G., Dwyer, J.T., Frydrych, A., Leung, J., Poole, D. & Hemodialysis (HEMO) Study Group (2002) Association of nutritional markers with physical and mental health status in prevalent hemodialysis patients from the HEMO study. *J. Ren. Nutr.* **12**, 160–169.
- Almeida, A.I., Correia, M., Camilo, M. & Ravasco, P. (2013) Length of stay in surgical patients: nutritional predictive parameters revisited. *Br. J. Nutr.* **109**, 322–328.
- Anunciação, P.C., Ribeiro, R.C.L., Pereira, M.Q. & Comunian, M. (2014) Different measurements of waist circumference and sagittal abdominal diameter and their relationship with cardiometabolic risk factors in elderly men. *J. Hum. Nutr. Diet.* **27**, 162–167.
- Ashwell, M., Lejeune, S. & McPherson, K. (1996) Ratio of waist circumference to height may be better indicator of need for weight management. *BMJ* **312**, 377.
- Ashwell, M., Gunn, P. & Gibson, S. (2012) Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obes. Rev.* **13**, 275–286.
- Auyeung, T.W., Lee, J.S., Kwok, T., Leung, J., Leung, P.C. & Woo, J. (2009) Estimation of stature by measuring fibula and ulna bone length in 2443 older adults. *J. Nutr. Health Aging* **13**, 931–936.
- Baldwin, C. & Weekes, C.E. (2011) Dietary advice with or without oral nutritional supplements for disease-related malnutrition in adults. *Cochrane Database Syst. Rev.* **7**, CD002008.
- Bannerman, E., Reilly, J.J., MacLennan, W.J., Kirk, T. & Pender, F. (1997) Evaluation of validity of British anthropometric reference data for assessing nutritional state of elderly people in Edinburgh: cross sectional study. *BMJ* **315**, 338–341.
- BAPEN. (2012) The MUST report – nutritional screening of adults: a multidisciplinary responsibility. Executive summary. Available at: <http://www.bapen.org.uk/screening-for-malnutrition/must/must-report/the-must-report-executive-summary> (accessed on 28 August 2014).
- Bassey, E.J. (1986) Demi-span as a measure of skeletal size. *Ann. Hum. Biol.* **13**, 499–502.
- Bellizzi, V., Scalfi, L., Terracciano, V., De Nicola, L., Minutolo, R., Marra, M., Guida, B., Cianciaruso, B., Conte, G. & Di Iorio, B.R. (2006) Early changes in bioelectrical estimates of body composition in chronic kidney disease. *J. Am. Soc. Nephrol.* **17**, 1481–1487.
- Bergman, R.N., Stefanovski, D., Buchanan, T.A., Sumner, A.E., Reynolds, J.C., Sebring, N.G., Xiang, A.H. & Watanabe, R.M. (2011) A better index of body adiposity. *Obesity* **19**, 1083–1089.
- Berkhout, A.M., Cools, H.J. & Mulder, J.D. (1989) [Measurement or estimation of body length in older nursing home patients.]. *Tijdschr. Gerontol. Geriatr.* **20**, 211–214.
- Biehl, A., Hovengen, R., Meyer, H.E., Hjelmestaeth, J., Meisjord, J., Grøholt, E.K., Roelants, M. & Strand, B.H. (2013) Impact of instrument error on the estimated prevalence of overweight and obesity in population-based surveys. *BMC Public Health* **13**, 146.
- Bishop, C.W., Bowen, P.E. & Ritchey, S.J. (1981) Norms for nutritional assessment of American adults by upper arm anthropometry. *Am. J. Clin. Nutr.* **34**, 2530–2539.
- Brown, J.K., Whittemore, K.T. & Knapp, T.R. (2000) Is arm span an accurate measure of height in young and middle-age adults? *Clin. Nurs. Res.* **9**, 84–94.
- Burden, S.T., Stoppard, E., Shaffer, J., Makin, A. & Todd, C. (2005) Can we use mid upper arm anthropometry to detect malnutrition in medical inpatients? A validation study. *J. Hum. Nutr. Diet.* **18**, 287–294.
- Burgert, S.L. & Anderson, C.F. (1979) A comparison of triceps skinfold values as measured by the plastic McGaw calliper and the Lange calliper. *Am. J. Clin. Nutr.* **32**, 1531–1533.
- Burr, M.L. & Phillips, K.M. (1984) Anthropometric norms in the elderly. *Br. J. Nutr.* **51**, 165–169.
- Burton, R.F. (2010) Measures of adiposity: the inappropriate use of the fat mass index. *Int. J. Obes.* **34**, 213.
- Byrd, J., Langford, A., Paden, S.J., Plackemeier, W., Seidelman, C., Valla, M. & Wills, R. (2011) Scale consistency study: how accurate are inpatient hospital scales? *Nursing* **41**, 21–24.



- Capderou, A., Berkani, M., Becquermin, M.H. & Zelter, M. (2011) Reconsidering the arm span-height relationship in patients referred for spirometry. *Eur. Respir. J.* **37**, 157–163.
- Carin-Levy, G., Greig, C.A., Lewis, S.J., Stewart, A., Young, A. & Mead, G.E. (2008) The effect of different body positions on anthropometric measurements and derived estimates of body composition. *Int. J. Body Compos. Res.* **6**, 17–20.
- Carr, A.J., Jefferson, R.J., Weisz, I. & Turner-Smith, A.R. (1989) Correction of body height in scoliotic patients using ISIS scanning. *Spine* **14**, 220–222.
- Carter, O.D. & Haynes, S.G. (1987) Prevalence rates for scoliosis in US adults: results from the first National Health and Nutrition Examination Survey. *Int. J. Epidemiol.* **16**, 537–544.
- Centers for Disease Control and Prevention. (2005) NHANES anthropometry and physical activity monitor procedures manual. Available at: [http://www.cdc.gov/nchs/data/nhanes/nhanes\\_05\\_06/BM.pdf](http://www.cdc.gov/nchs/data/nhanes/nhanes_05_06/BM.pdf) (accessed on 28 August 2014).
- Cereda, E., Pedrolli, C., Zagami, A., Vanotti, A., Piffer, S., Opizzi, A., Rondanelli, M. & Caccialanza, R. (2011) Body mass index and mortality in institutionalized elderly. *J. Am. Med. Dir. Assoc.* **12**, 174–178.
- Chan, C., Smith, D., Spanel, P., McIntyre, C.W. & Davies, S.J. (2008) A non-invasive, on-line deuterium dilution technique for the measurement of total body water in haemodialysis patients. *Nephrol. Dial. Transplant.* **23**, 2064–2070.
- Charles, M.N. & Yen, D. (2000) Properties of a hybrid plaster-fibreglass cast. *Can. J. Surg.* **43**, 365–367.
- Chen, B.B., Shih, T.T., Hsu, C.Y., Yu, C.W., Wei, S.Y., Chen, C.Y., Wu, C.H. & Chen, C.Y. (2011) Thigh muscle volume predicted by anthropometric measurements and correlated with physical function in older adults. *J. Nutr. Health Aging* **15**, 433–438.
- Chumlea, W.C. & Guo, S. (1992) Equations for predicting stature in white and black elderly individuals. *J. Gerontol.* **47**, M197–M203.
- Chumlea, W.C., Guo, S.S., Wholihan, K., Cockram, D., Kuczmarski, R.J. & Johnson, C.L. (1998) Stature prediction equations for elderly non-Hispanic white, non-Hispanic black, and Mexican-American persons developed from NHANES III data. *J. Am. Diet. Assoc.* **98**, 137–142.
- Cole, T.J., Henson, G.L., Tremble, J.M. & Colley, N.V. (1997) Birthweight for length: ponderal index, body mass index or Bann index? *Ann. Hum. Biol.* **24**, 289–298.
- Coles, R.J., Clements, D.G. & Evans, W.D. (1994) Measurement of height: practical considerations for the study of osteoporosis. *Osteoporosis Int.* **4**, 353–356.
- Connor Gorber, S., Tremblay, M., Moher, D. & Gorber, B. (2007) A comparison of direct vs self-report measures for assessing height, weight and body mass index: a systematic review. *Obes. Rev.* **8**, 307–326.
- Corish, C.A. & Kennedy, N.P. (2003) Anthropometric measurements from a cross sectional survey of Irish free living elderly subjects with smoothed centile curves. *Br. J. Nutr.* **89**, 137–145.
- Corish, C.A., Flood, P., Mulligan, S. & Kennedy, N.P. (2000) Apparent low frequency of undernutrition in Dublin hospital in-patients: show we review the anthropometric thresholds for clinical practice? *Br. J. Nutr.* **84**, 325–335.
- Department of Health. (2012) National Diet and Nutrition Survey: headline results from years 1, 2 and 3 (combined) of the rolling programme 2008/9-2010/11. Available at: <https://www.gov.uk/government/publications/national-diet-and-nutrition-survey-headline-results-from-years-1-2-and-3-combined-of-the-rolling-programme-200809-201011> (accessed on 28 August 2014). (see appendix i).
- Deurenberg, P., Deurenberg Yap, M., Wang, J., Lin, F.P. & Schmidt, G. (1999) The impact of body build on the relationship between body mass index and percent body fat. *Int. J. Obes. Relat. Metab. Disord.* **23**, 537–542.
- Dey, D.K., Rothenberg, E., Sundh, V., Bosaeus, I. & Steen, B. (1999) Height and body weight in the elderly. A 25-year longitudinal study of a population aged 70 to 95 years. *Eur. J. Clin. Nutr.* **53**, 905–914.
- Duarte Pimentel, G., Portero-McLellan, K.C., Maesta, N., Corrente, J.E. & Burini, R.C. (2010) Accuracy of sagittal abdominal diameter as a predictor of abdominal fat among Brazilian adults: a comparison with waist circumference. *Nutr. Hosp.* **25**, 656–661.
- Dunn, J.E., Link, C.L., Felson, D.T., Crincoli, M.G., Keysor, J.J. & McKinlay, J.B. (2004) Prevalence of foot and ankle conditions in a multiethnic community sample of older adults. *Am. J. Epidemiol.* **159**, 491–498.
- Durnin, J.V.G.A. & Womersley, J. (1974) Body fat assessed from total body density and its estimation from skinfold thickness. *Br. J. Nutr.* **32**, 77–97.
- Dylke, E.S., Yee, J., Ward, L.C., Foroughi, N. & Kinbreath, S.L. (2012) Normative volume difference between the dominant and nondominant upper limbs in healthy older women. *Lymphat. Res. Biol.* **10**, 182–188.
- Elia, M. (2003) *The 'MUST' Report. Nutritional Screening of Adults: A Multidisciplinary Responsibility. Development and Use of the 'Malnutrition Universal Screening Tool' ('MUST') for adults. Malnutrition Advisory Group (MAG), a Standing Committee of the British Association of Parenteral and Enteral Nutrition (BAPEN)*. Redditch: BAPEN.
- Enoki, H., Kuzuya, M., Masuda, Y., Hirakawa, Y., Iwata, M., Hasegawa, J., Izawa, S. & Iguchi, A. (2007) Anthropometric measurements of mid-upper arm as a mortality predictor for community-dwelling Japanese elderly: the Nagoya Longitudinal Study of Frail Elderly (NLS-FE). *Clin. Nutr.* **26**, 597–604.
- Falagas, M.E., Athanasoulia, A.P., Peppas, G. & Karageorgopoulos, D.E. (2009) Effect of body mass index on the outcome of infections: a systematic review. *Obes. Rev.* **10**, 280–289.
- Finch, H. & Arumugam, V. (2014) Assessing the accuracy and reliability of direct height measurement for use in adult neurological patients with contractures: a comparison with

- height from ulna length. *J. Hum. Nutr. Diet.* **27**(Suppl. 2), 48–56.
- Flegal, K.M. & Graubard, B.I. (2009) Estimates of excess death associated with body mass index and other anthropometric variables. *Am. J. Clin. Nutr.* **89**, 1213–1219.
- Flegal, K.M., Kit, B.K., Orpana, H. & Graubard, B.I. (2013) Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. *JAMA* **309**, 71–82.
- Forbes, G.B., Brown, M.R. & Griffiths, H.J. (1988) Arm muscle plus bone area: anthropometry and CAT scan compared. *Am. J. Clin. Nutr.* **47**, 929–931.
- Ford, E.S., Mokdad, A.H. & Giles, W.H. (2003) Trends in waist circumference among US adults. *Obes. Res.* **11**, 1223–1231.
- Frid, H., Adolfson, E.T., Rosenblad, A. & Nydahl, M. (2013) Agreement between different methods of measuring height in elderly patients. *J. Hum. Nutr. Diet.* **26**, 504–511.
- Frisancho, A.R. (1974) Triceps skinfold and upper arm muscle size norms for assessment of nutritional status. *Am. J. Clin. Nutr.* **27**, 1052–1057.
- Frisancho, A.R. (2008) *Anthropometric Standards: An Interactive Nutritional Reference of Body Size and Body Composition for Children and Adults*, 2nd edn. Ann Arbor, MI: University of Michigan Press.
- Gassull, M.A., Cabré, E., Vilar, L., Alastrue, A. & Montserrat, A. (1984) Protein-energy malnutrition: an integral approach and a simple new classification. *Hum. Nutr. Clin. Nutr.* **38**, 419–431.
- Geeta, A., Jamaiyah, H., Safiza, M.N., Khor, G.L., Kee, C.C., Ahmad, A.Z., Suzana, S., Rahman, R. & Faudzi, A. (2009) Reliability, technical error of measurements and validity of instruments for nutritional status assessment of adults in Malaysia. *Singapore Med. J.* **50**, 1013–1018.
- Gibson, R.S. (2005) *Principles of nutritional assessment*, 2nd edn. Oxford: Oxford University Press.
- Gletsu-Miller, N., Kahn, H.S., Gasevic, D., Liang, Z., Frediani, J.K., Torres, W.E., Ziegler, T.R., Phillips, L.S. & Lin, E. (2013) Sagittal abdominal diameter and visceral adiposity: correlates of beta-cell function and dysglycemia in severely obese women. *Obes. Surg.* **23**, 874–881.
- Gray, G.E. & Gray, L.K. (1979) Validity of anthropometric norms used in the assessment of hospitalized patients. *J. Parenter. Enteral Nutr.* **3**, 366–368.
- Green, C.J., Campbell, I.T., McClelland, P., Hutton, J.L., Ahmed, M.M., Helliwell, T.R., Wilkes, R.G., Gilbertson, A.A. & Bone, J.M. (1995) Energy and nitrogen balance and changes in mid upper-arm circumference with multiple organ failure. *Nutrition* **11**, 739–746.
- Guerra, R.S., Fonseca, I., Pichel, F., Restivo, M.T. & Amarra, T.F. (2014) Hand length as an alternative measurement of height. *Eur. J. Clin. Nutr.* **68**, 229–233.
- Gupta, R., Knobel, D., Gunabushanam, V., Agaba, E., Ritter, G., Marini, C. & Barrera, R. (2011) The effect of low body mass index on outcome in critically ill surgical patients. *Nutr. Clin. Pract.* **26**, 593–597.
- Gurney, J.M. & Jelliffe, D.B. (1973) Arm anthropometry in nutritional assessment: nomogram for rapid calculation of muscle circumference and cross-sectional muscle and fat areas. *Am. J. Clin. Nutr.* **26**, 912–915.
- Han, T.S. & Lean, M.E. (1996) Lower leg length as an index of stature in adults. *Int. J. Obes. Relat. Metab. Disord.* **20**, 21–27.
- Hartz, A.J., Rupley, D.C. Jr, Kalkhoff, R.D. & Rimm, A.A. (1983) Relationship of obesity to diabetes: influence of obesity level and body fat distribution. *Prev. Med.* **12**, 351–357.
- Harvey, K.B., Moldawer, L.L., Bistrrian, B.R. & Blackburn, G.L. (1981) Biological measures for the formulation of a hospital prognostic index. *Am. J. Clin. Nutr.* **34**, 2013–2022.
- Hecking, M., Karaboyas, A., Antlanger, M., Saran, R., Wizemann, V., Chazot, C., Rayner, H., Hörl, W.H., Pisoni, R.L., Robinson, B.M., Sunder-Plassmann, G., Moissi, U., Kotanko, P., Levin, N.W., Säemann, M.D., Kalantar-Zadeh, K., Port, F.K. & Wabel, P. (2013) Significance of interdialytic weight gain versus chronic volume overload: consensus opinion. *Am. J. Nephrol.* **38**, 78–90.
- Hendershot, K.M., Robinson, L., Roland, J., Vaziri, K., Rizzo, A.G. & Fakhry, S.M. (2006) Estimating height, weight and body mass index: implications for research and patient safety. *J. Am. Coll. Surg.* **203**, 887–893.
- Henry, C.J. (2005) Basal metabolic rate studies in humans: measurement and development of equations. *Public Health Nutr.* **8**, 1133–1152.
- Heymsfield, S.B., McManus, C., Smith, J., Stevens, V. & Nixon, D.W. (1982) Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. *Am. J. Clin. Nutr.* **36**, 680–690.
- Hickson, M. & Frost, G. (2003) A comparison of three methods for estimating height in the acutely ill elderly population. *J. Hum. Nutr. Diet.* **16**, 13–20.
- Hirani, V. & Aresu, M. (2012) Development of new demi-span equations from a nationally representative sample of older people to estimate adult height. *J. Am. Geriatr. Soc.* **60**, 550–554.
- de Hollander, E.L., Bemelmans, W.J. & de Groot, L.C. (2013) Associations between changes in anthropometric measures and mortality in old age: a role for mid-upper arm circumference? *J. Am. Med. Dir. Assoc.* **14**, 187–193.
- Houghton, J.J. & Smith, S. (2011) The accuracy of mid upper arm circumference as an estimate of body mass index in healthy female adults. *Proc. Nutr. Soc.* **70**, E260.
- Huang, C.X., Tighiouart, H., Beddhu, S., Cheung, A.K., Dwyer, J.T., Eknayan, G., Beck, G.J., Levey, A.S. & Sarnak, M.J. (2010) Both low muscle mass and low fat are associated with higher all-cause mortality in hemodialysis patients. *Kidney Int.* **77**, 624–629.
- Huxley, R., Mendis, S., Zheleznyakov, E., Reddy, S. & Chan, J. (2010) Body mass index, waist circumference and waist : hip ratio as predictors of cardiovascular risk – a review of the literature. *Eur. J. Clin. Nutr.* **64**, 16–22.
- Jackson, A.S. & Pollock, M.L. (1978) Generalised equations for predicting body density in men. *Br. J. Nutr.* **40**, 497–504.

- Jackson, A.S., Pollock, M.L. & Ward, A. (1980) Generalised equations for predicting body density in women. *Med. Sci. Sports Exerc.* **12**, 175–182.
- James, W.P.T., Mascie-Taylor, C.G.N., Norgan, N.G., Bistran, B.R., Shetty, P.S. & Ferro-Luzzi, A. (1994) The value of arm circumference measurements in assessing chronic energy deficiency in Third World adults. *Eur. J. Clin. Nutr.* **48**, 883–894.
- Janghorbani, M., Momeni, F. & Dehghani, M. (2012) Hip circumference, height and risk of type 2 diabetes: systematic review and meta-analysis. *Obes. Rev.* **13**, 1172–1181.
- Janssen, I., Heymsfield, S.B., Wang, Z.M. & Ross, R. (2000) Skeletal muscle mass and distribution in 468 men and women aged 18–88 years. *J. Appl. Physiol.* **89**, 81–88.
- Jensen, T.G., Dudrick, S.J. & Johnston, D.A. (1981) A comparison of triceps skinfold and upper arm circumference measurements taken in standard and supine positions. *J. Parenter. Enteral Nutr.* **5**, 519–521.
- Keys, A., Fidanza, F., Karvonen, M.J., Kimura, N. & Taylor, H.L. (1972) Indices of relative weight and obesity. *J. Chronic Dis.* **25**, 329–343.
- Krakauer, N.Y. & Krakauer, J.C. (2012) A new body shape index predicts mortality hazard independently of body mass index. *PLoS ONE* **7**, e39504. doi:10.1371/journal.pone.0039504.
- Krishan, K. (2011) Marked limb bilateral asymmetry in an agricultural endogamous population of North India. *Am. J. Hum. Biol.* **23**, 674–685.
- Kuczmarski, M.F., Kuczmarski, R.J. & Najjar, M. (2000) Descriptive anthropometric reference data for older Americans. *J. Am. Diet. Assoc.* **100**, 59–66.
- Kuk, J.L., Katzmarzyk, P.T., Nichaman, M.Z., Church, T.S., Blair, S.N. & Ross, R. (2006) Visceral fat is an independent predictor of all-cause mortality in men. *Obesity* **14**, 336–341.
- Kullberg, J., von Below, C., Lonn, L., Lind, L., Ahlstrom, H. & Johansson, L. (2007) Practical approach for estimation of subcutaneous and visceral adipose tissue. *Clin. Physiol. Funct. Imaging* **27**, 148–153.
- Landi, F., Russo, A., Liperoti, R., Pahor, M., Tosato, M., Capoluongo, E., Bernabei, R. & Onder, G. (2010) Midarm muscle circumference, physical performance and mortality: results from the aging and longevity study in the Sirente geographic area (iSIRENTE study). *Clin. Nutr.* **29**, 441–447.
- Landi, F., Onder, G., Russo, A., Liperoti, R., Tosato, M., Martone, A.M., Capoluongo, E. & Bernabei, R. (2014) Calf circumference, frailty and physical performance among older adults living in the community. *Clin. Nutr.* **33**, 539–544.
- Lanska, D.J., Lanska, M.J., Hartz, A.J. & Rimm, A.A. (1985) Factors influencing anatomic location of fat tissue in 52,953 women. *Int. J. Obes.* **9**, 29–38.
- Larsson, B., Svärdsudd, K., Welin, L., Wilhelmsen, L., Björntorp, P. & Tibblin, G. (1984) Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow up of participants in the study of men born in 1913. *Br. Med. J.* **288**, 1401–1404.
- Larsson, I., Henning, B., Lindroos, A.K., Näslund, I., Sjöström, C.D. & Sjöström, L. (2006) Optimized predictions of absolute and relative amounts of body fat from weight, height, other anthropometric predictors, and age. *Am. J. Clin. Nutr.* **83**, 252–259.
- Launer, L.J. & Harris, T. (1996) Weight, height and body mass index distributions in geographically and ethnically diverse samples of older persons. *Age Ageing* **25**, 300–306.
- Leandro-Merhi, V.A., de Aquino, J.L. & Sales Chagas, J.F. (2011) Nutrition status and risk factors associated with length of hospital stay for surgical patients. *J. Parenter. Enteral Nutr.* **35**, 241–248.
- Lehmann, A.B., Bassey, E.J., Morgan, K. & Dallosso, H.M. (1991) Normal values for weight, skeletal size and body mass indices in 890 men and women aged over 65 years. *Clin. Nutr.* **10**, 18–22.
- Lohman, T., Roche, A.F. & Martorell, R. (1988) *Anthropometric standardization reference manual*. Champaign, IL: Human Kinetics.
- de Lucia, E., Lemma, F., Tesfaye, F., Demisse, T. & Ismail, S. (2002) The use of armspan measurement to assess the nutritional status of adults in four Ethiopian ethnic groups. *Eur. J. Clin. Nutr.* **56**, 91–95.
- Madden, A.M., Tsikoura, T. & Stott, D.J. (2012) The estimation of body height from ulna length in healthy adults from different ethnic groups. *J. Hum. Nutr. Diet.* **25**, 121–128.
- McDowell, M.A., Fryar, C.D., Ogden, C.L. & Flegal, K.M. (2008) Anthropometric reference data for children and adults: United States, 2003–2006. Available at: <http://www.cdc.gov/nchs/data/nhsr/nhsr010.pdf> (accessed on 28 August 2014).
- McWhirter, J.P. & Pennington, C.R. (1994) Incidence and recognition of malnutrition in hospital. *BMJ* **308**, 945–948.
- Mendenhall, C.L. (1992) Protein-calorie malnutrition in alcoholic liver disease. In *Nutrition and Alcohol*. eds R.R. Watson & B. Watzl, pp. 363–384. Boca Raton, FL: CRC Press.
- Meredith, S. & Madden, A.M. (2014) Categorisation of health risk associated with excessive body weight identified using body mass Index, a body shape index and waist circumference. *Eur. J. Nutr. Food Saf.* **4**, 185–186.
- Miller, M.D., Crotty, M., Giles, L.C., Bannerman, E., Whitehead, C., Cobiac, L., Daniels, L.A. & Andrews, G. (2002) Corrected arm muscle area: an independent predictor of long-term mortality in community-dwelling older adults? *J. Am. Geriatr. Soc.* **50**, 1272–1277.
- Mohanty, S.P., Babu, S.S. & Nair, N.S. (2001) The use of arm span as a predictor of height: a study of South Indian women. *J. Orthop. Surg.* **9**, 19–23.
- Moreno, L.A., Rodríguez, G., Guillén, J., Rabanaque, M.J., León, J.F. & Ariño, A. (2002) Anthropometric measurements in both sides of the body in the assessment of nutritional status in prepubertal children. *Eur. J. Clin. Nutr.* **56**, 1209–1215.

- Morgan, M.Y., Madden, A.M., Jennings, G., Elia, M. & Fuller, N.J. (2006) Two-component models are of limited value for the assessment of body composition in patients with cirrhosis. *Am. J. Clin. Nutr.* **84**, 1151–1162.
- NICE. (2013) Assessing body mass index and waist circumference thresholds for intervening to prevent ill health and premature death among adults from black, Asian and other minority ethnic groups in the UK. NICE public health guidance 46. Available at: <http://guidance.nice.org.uk/PH46> (accessed on 28 August 2014).
- de Onis, M. & Habicht, J.P. (1996) Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. *Am. J. Clin. Nutr.* **64**, 650–658.
- Osterkamp, L.K. (1995) Current perspective on assessment of human body proportions of relevance to amputees. *J. Am. Diet. Assoc.* **95**, 215–218.
- Pai, M.P. (2012) Drug dosing based on weight and body surface area: mathematical assumptions and limitations in obese adults. *Pharmacotherapy* **32**, 856–868.
- Park, S.W., Goodpaster, B.H., Strotmeyer, E.S., Kuller, L.H., Broudeau, R., Kammerer, C., deRekeneire, N., Harris, T.B., Schwartz, A.V., Tylavsky, F.A., Cho, Y.W. & Newman, A.B. & the Health, Aging and Body Composition Study. (2007) Accelerated loss of skeletal muscle strength in older adults with type 2 diabetes. *Diabetes Care* **30**:1507–1512.
- Payette, H., Kergoat, M.J., Shatenstein, B., Boutier, V. & Nadon, S. (2000) Validity of self-reported height and weight estimates in cognitively-intact and impaired elderly individuals. *J. Nutr. Health Aging* **4**, 223–228.
- Perini, T.A., de Oliveira, G.L., Ornellas, J.D. & de Oliveira, F.P. (2005) Technical error of measurement in anthropometry. *Rev. Bras. Med. Esporte* **11**, 86–90.
- Powell-Tuck, J. & Hennessy, E.M. (2003) A comparison of mid upper arm circumference, body mass index and weight loss as indices of undernutrition in acutely hospitalised patients. *Clin. Nutr.* **22**, 307–312.
- Quetelet, A.D. (1869) *Physique sociale. Ou, essai sur le développement des facultés de l'homme*. Brussels: C. Muquardt.
- Reeves, S.L., Varakamin, C. & Henry, C.J.K. (1996) The relationship between arm-span measurement and height with special reference to gender and ethnicity. *Eur. J. Clin. Nutr.* **50**, 398–400.
- Reid, C.L., Campbell, I.T. & Little, R.A. (2004) Muscle wasting and energy balance in critical illness. *Clin. Nutr.* **23**, 273–280.
- Reidlinger, D.P., Willis, J.M. & Whelan, K. (2014) Resting metabolic rate and anthropometry in older people: a comparison of measured and calculated values. *J. Hum. Nutr. Diet.* doi:10.1111/jhn.12215.
- Renahan, A.G., Tyson, M., Egger, M., Heller, R.F. & Zwahlen, M. (2008) Body-mass index and incidence of cancer: a systematic review and meta-analysis of prospective observational studies. *Lancet* **371**, 569–578.
- Risérus, U., de Faire, U., Berglund, L. & Hellenius, M.L. (2010) Sagittal abdominal diameter as a screening tool in clinical research. *J. Obes.* Article ID 757939, 7 pages, 2010. doi:10.1155/2010/757939.
- Ritz, P. (2004) Validity of measuring knee-height as an estimate of height in diseased French elderly persons. *J. Nutr. Health Ageing* **8**, 386–388.
- Rolland, Y., Lauwers-Cances, V., Cournot, M., Nourshahémi, F., Reynish, W., Rivière, D., Vellas, B. & Grandjean, H. (2003) Sarcopenia, calf circumference and physical function of elderly women: a cross sectional study. *J. Am. Geriatr. Soc.* **51**, 1120–1124.
- Ross, R., Berentzen, T., Bradshaw, A.J., Janssen, I., Kahn, H.S., Katzmarzyk, P.T., Kuk, J.L., Seidell, J.C., Snijder, M.B., Sørensen, T.I. & Després, J.P. (2008) Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? *Obes. Rev.* **9**, 312–325.
- Scalfi, L., Polito, A., Bianchi, L., Marra, M., Caldara, A., Nicolai, E. & Contaldo, F. (2002) Body composition changes in patients with anorexia nervosa after complete weight recovery. *Eur. J. Clin. Nutr.* **56**, 15–20.
- Schell, L.M., Johnston, F.E., Smith, D.R. & Paolone, A.M. (1985) Directional asymmetry of body dimensions among white adolescents. *Am. J. Phys. Anthropol.* **67**, 317–322.
- Schmidt, P.K. & Carter, J.E. (1990) Static and dynamic differences among five types of skinfold callipers. *Hum. Biol.* **62**, 369–388.
- Schutz, Y., Kyle, U.U. & Pichard, C. (2002) Fat-free mass index and fat mass index percentiles in Caucasians aged 18–98 y. *Int. J. Obes. Relat. Metab. Disord.* **26**, 953–960.
- Schwab, F., Dubey, A., Gamez, L., El Fegoun, A.B., Hwang, K., Pagala, M. & Farcy, J.P. (2005) Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine* **30**, 1082–1085.
- Shahar, S. & Pooy, N.S. (2003) Predictive equations for estimation of stature in Malaysian elderly people. *Asia Pac. J. Clin. Nutr.* **12**, 80–84.
- Skipper, A., Ferguson, M., Thompson, K., Castellanos, V.H. & Porcari, J. (2012) Nutrition screening tools: an analysis of the evidence. *J. Parenter. Enteral Nutr.* **36**, 292–298.
- Smith, S., Davidson, H.I.M. & Jenkins, D.A.S. (2005) Prediction of fat free mass in long term haemodialysis patients using dual x-ray absorptiometry (DXA) as the reference method. *Proc. Nutr. Soc.* **64** (Suppl. 2A).
- Snijder, M.B., Nicolaou, M., van Valkengoed, I.G., Brewster, L.M. & Stronks, K. (2012) Newly proposed body adiposity index (BAI) by Bergman et al. is not strongly related to cardiovascular health risk. *Obesity* **20**, 1138–1139.
- Soler-Cataluña, J.J., Sánchez-Sánchez, L., Martínez-García, M.A., Sánchez, P.R., Salcedo, E. & Navarro, M. (2005) Mid-arm muscle area is a better predictor of mortality than body mass index in COPD. *Chest* **128**, 2108–2115.
- Sonnenschein, E.G., Kim, M.Y., Pasternack, B.S. & Tonioli, P.G. (1993) Sources of variability of waist and hip



- measurements in middle-aged women. *Am. J. Epidemiol.* **138**, 301–309.
- Sorkin, J.D., Muller, D.C. & Andres, R. (1999) Longitudinal change in the heights of men and women: consequential effects on body mass index. *Epidemiol. Rev.* **21**, 247–260.
- Steele, M.F. & Chenier, T.C. (1990) Arm-span, height, and age in black and white women. *Ann. Hum. Biol.* **17**, 533–541.
- Stevens, J., Truesdale, K.P., McClain, J.E. & Cai, J. (2006) The definition of weight maintenance. *Int. J. Obes.* **30**, 391–399.
- Stewart, A.D. & Sutton, L. (2012) *Body Composition in Sport, Exercise and Health*. Abingdon: Routledge.
- Stewart, A.D., Stewart, A. & Reid, D.M. (2002) Correcting calf girth discriminates the incidence of falling but not bone mass by broadband ultrasound attenuation in elderly adult females. *Bone* **31**, 195–198.
- Stewart, T., Cheong, W., Barr, V. & Tang, D. (2009) Strong and light plaster casts? *Injury* **40**, 890–893.
- Stothart, J.P. & McGill, S.M. (2000) Stadiometry: on measurement technique to reduce variability in spine shrinkage measurement. *Clin. Biomech.* **15**, 546–548.
- Stratton, R.J., Dixon, R., Longmore, D., Stroud, M. & Elia, M. (2003a) Effect of recalled weight and height on malnutrition risk. *Clin. Nutr.* **22**(Suppl. 1), S9–S10.
- Stratton, R.J., Green, C.J. & Elia, M. (2003b) *Disease-related malnutrition*. Wallingford: CABI Publishing.
- Sungurtekin, H., Sungurtekin, U., Oner, O. & Okke, D. (2008) Nutritional assessment in critically ill patients. *Nutr. Clin. Pract.* **23**, 635–641.
- Taylor, A.E., Ebrahim, S., Ben-Shlomo, Y., Martin, R.M., Whincup, P.H., Yarnell, J.W., Wannamethee, S.G. & Lawlor, D.A. (2010) Comparison of the associations of body mass index and measures of central adiposity and fat mass with coronary heart disease, diabetes, and all-cause mortality: a study using data from 4 UK cohorts. *Am. J. Clin. Nutr.* **91**, 547–556.
- Thomas, E.L., Parkinson, J.R., Frost, G.S., Goldstone, A.P., Doré, C.J., McCarthy, J.P., Collins, A.L., Fitzpatrick, J.A., Durighel, G., Taylor-Robinson, S.D. & Bell, J.D. (2012) The missing risk: MRI and MRS phenotyping of abdominal adiposity and ectopic fat. *Obesity* **20**, 76–87.
- Thuluvath, P.J. & Triger, D.R. (1995) How valid are our reference standards of nutrition? *Nutrition* **11**, 731–733.
- Todorovic, V., Russell, C. & Elia, M. (2011) The MUST explanatory booklet. Available at: [http://www.bapen.org.uk/pdfs/must/must\\_explan.pdf](http://www.bapen.org.uk/pdfs/must/must_explan.pdf) (accessed on 28 August 2014).
- Trowbridge, F.L., Hiner, C.D. & Robertson, A.D. (1982) Arm muscle indicators and creatinine excretion in children. *Am. J. Clin. Nutr.* **36**, 691–696.
- UK Statutory Instrument. (2000) *Weights and measures: the non-automatic weighing instruments regulations*. London: HMSO. (S.I. No. 3236). Available at: <http://www.legislation.gov.uk/ukSI/2000/3236/contents/made> (accessed on 28 August 2014).
- Ulijaszek, S.J. & Kerr, D.A. (1999) Anthropometric measurement error and the assessment of nutritional status. *Br. J. Nutr.* **82**, 165–177.
- Valente de Silva, H.G., Santos, S.O., Silva, N.O., Ribeiro, F.D., Josua, L.L. & Moreira, A.S. (2012) Nutritional assessment associated with length of inpatients' hospital stay. *Nutr. Hosp.* **27**, 542–547.
- Valsamakis, G., Chetty, R., Anwart, A., Banerjee, A.K., Barnett, A. & Kumar, S. (2004) Association of simple anthropometric measures of obesity with visceral fat and the metabolic syndrome in male Caucasian and Indo-Asian subjects. *Diabet. Med.* **21**, 1339–1345.
- Van Lier, A.M., Roy, M.A. & Payette, H. (2007) Knee height to predict stature in North American Caucasian frail free-living elderly receiving community services. *J. Nutr. Health Aging* **11**, 372–379.
- Van Thiel, D.H., Moore, C.M., Garcia, M., George, M. & Nadir, A. (2011) Continuous peritoneal drainage of large-volume ascites. *Dig. Dis. Sci.* **56**, 2723–2727.
- van Venrooij, L.M., de Vos, R., Borgmeijer-Hoelen, M.M., Haaring, C. & de Mol, B.A. (2008) Preoperative unintended weight loss and low body mass index in relation to complications and length of stay after cardiac surgery. *Am. J. Clin. Nutr.* **87**, 1656–1661.
- Villamor, E., Saathoff, E., Mugusi, F., Bosch, R.J., Urassa, W. & Fawzi, W.W. (2006) Wasting and body composition of adults with pulmonary tuberculosis in relation to HIV-1 coinfection, socioeconomic status and severity of tuberculosis. *Eur. J. Clin. Nutr.* **60**, 163–171.
- Vivanti, A., Yu, L., Palmer, M., Dakin, L., Sun, J. & Campbell, K. (2013) Short-term body weight fluctuations in older well-hydrated hospitalised patients. *J. Hum. Nutr. Diet.* **26**, 429–435.
- Voss, L.D. & Bailey, B.J. (1994) Equipping the community to measure children's height: the reliability of portable instruments. *Arch. Dis. Child.* **70**, 469–471.
- Voss, L.D., Bailey, B.J., Cumming, K., Wilkin, T.J. & Betts, P.R. (1990) The reliability of height measurement (the Wessex Growth Study). *Arch. Dis. Child.* **65**, 1340–1344.
- Vulcano, D.S., Carvalhaes, M.A. & Bakonyi Neto, A. (2013) Evaluation of nutritional indices and body composition in patients with advanced liver disease enrolled for liver transplantation. *Acta Cir. Bras.* **28**, 733–739.
- Wang, J., Thornton, J.C., Bari, S., Williamson, B., Gallagher, D., Heymsfield, S.B., Horlick, M., Kotler, D., Laferrère, B., Mayer, L., Pi-Sunyer, F.X. & Pierson, R.N. Jr (2003) Comparisons of waist circumferences measured at four sites. *Am. J. Clin. Nutr.* **77**, 379–384.
- Watson, P.E. & Robinson, M.F. (1965) Variations in body-weight of young women during the menstrual cycle. *Br. J. Nutr.* **19**, 237–248.
- World Health Organization. (1995) Physical status: the use and interpretation of anthropometry. Available at: [http://whqlibdoc.who.int/trs/WHO\\_TRS\\_854.pdf](http://whqlibdoc.who.int/trs/WHO_TRS_854.pdf) (accessed on 28 August 2014).



World Health Organization. (2008) Waist circumference and waist-hip ratio. Available at: [http://whqlibdoc.who.int/publications/2011/9789241501491\\_eng.pdf](http://whqlibdoc.who.int/publications/2011/9789241501491_eng.pdf) (accessed on 28 August 2014).

World Health Organization. (2014) BMI classification. Available at: [http://apps.who.int/bmi/index.jsp?introPage=intro\\_3.html](http://apps.who.int/bmi/index.jsp?introPage=intro_3.html) (accessed on 28 August 2014).

Yim, J.Y., Kim, D., Lim, S.H., Park, M.J., Choi, S.H., Lee, C.H., Kim, S.S. & Cho, S.H. (2010) Sagittal abdominal diameter is a strong anthropometric measure of visceral adipose tissue in the Asian general population. *Diabetes Care* **33**, 2665–2670.