Skeletal muscle mass reference curves for children and adolescents

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What is already known about this subject

• Skeletal muscle is considered a major site of insulin-mediated glucose disposal and is thus a key tissue in whole-body glucose homeostasis.
• Low muscle mass and fitness is associated with metabolic risk and muscular strength is positively related to higher insulin sensitivity in children and adolescents.
• The use of skeletal muscle mass measurement in surveillance has been constrained by the absence of normative data that identifies individuals across the age spectrum with high or low amount of skeletal muscle.

What this study adds

• This study demonstrates that compartmental bio-impedance analysis provides a simple and non-invasive method for assessing muscle-to-fat ratios in children.
• Centile curves for appendicular skeletal muscle mass and fat-free mass have been added to the suite of charts available for assessing growth and body composition across childhood and adolescence.
• Muscle-to-fat ratio has been described and shows potential as an improved measure of metabolic risk.

Summary

Background: Skeletal muscle is key to motor development and represents a major metabolic end organ that aids glycaemic regulation.

Objectives: To create gender-specific reference curves for fat-free mass (FFM) and appendicular (limb) skeletal muscle mass (SMMa) in children and adolescents. To examine the muscle-to-fat ratio in relation to body mass index (BMI) for age and gender.

Methods: Body composition was measured by segmental bioelectrical impedance (BIA, Tanita BC418) in 1985 Caucasian children aged 5–18.8 years. Skeletal muscle mass data from the four limbs were used to derive smoothed centile curves and the muscle-to-fat ratio.

Results: The centile curves illustrate the developmental patterns of %FFM and SMMa. While the %FFM curves differ markedly between boys and girls, the SMMa (kg), %SMMa and %SMMa/FFM show some similarities in shape and variance, together with some gender-specific characteristics. Existing BMI curves do not reveal these gender differences. Muscle-to-fat ratio showed a very wide range with means differing between boys and girls and across fifths of BMI z-score.

Conclusions: BIA assessment of %FFM and SMMa represents a significant advance in nutritional assessment since these body composition components are associated with metabolic health. Muscle-to-fat ratio has the potential to provide a better index of future metabolic health.

Keywords: Bioelectrical impedance, centiles, fat-free mass, skeletal muscle mass.

Abbreviations: BMI, body mass index; MFR, muscle:fat ratio.

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Introduction

Measuring skeletal muscle mass (SMM) in children and adults is an important component of nutritional assessment, and is increasingly being recognized as an independent marker of metabolic health. Low muscle mass and fitness is associated with metabolic risk and muscular strength is positively related to higher insulin sensitivity in children and adolescents (1,2). Skeletal muscle is considered a major site of insulin-mediated glucose disposal and is thus a key tissue in whole-body glucose homeostasis, with insulin resistance at this site being particularly important (3). In addition, sarcopenia and sarcopenic obesity reflect a deficit or loss of SMM, with their origins beginning in early life and can also lead to an increased risk for the metabolic syndrome (4). A recent observation in adults revealed that a smaller thigh circumference (most likely reflecting a low thigh muscle mass) is associated with the development of cardiovascular morbidity and early mortality (5). However, the use of SMM measurement in surveillance has been constrained by the absence of normative data that identifies individuals across the age spectrum with high or low amounts of SMM (6). This is required both for clinical management of individuals and for longitudinal and cross-sectional surveillance of populations. Currently, quantifying whole-body SMM involves imaging techniques such as magnetic resonance imaging, and dual energy X-ray absorptiometry (DXA), whole-body Kc counting or biochemical assessment of 24-h creatinine excretion (7–9). These procedures can be time consuming, expensive, invasive for the subject and require trained expertise. Additionally, across childhood and adolescence, SMM increases together with overall increases in fat-free mass (FFM) during growth and development (10). This necessitates the use of centile curves with variable cut-off values for boys and girls at different ages, similar to those already in use for body mass index (BMI) and percentage body fat (11,12).

Bioelectrical impedance (BIA) offers a simple, rapid, non-invasive and affordable method for assessing body composition and is able to distinguish between fat mass (FM) and FFM on the basis of their differential electrical conductance and impedance characteristics (13). BIA offers practical advantages over laboratory-based body composition tools such as DXA since it is inexpensive, portable and quick and easy to use even though it is slightly less accurate. Furthermore, segmental analysers provide measures of FM and FFM separately for the trunk and limbs. The FFM in the limbs is further separated into SMM and hence offers a good proxy for total SMM. We term this appendicular skeletal muscle mass (SMMa). The potential of segmental BIA for quantifying SMMa has previously been assessed in children with DXA used as the criterion method (14). In that study, segmental BIA indices were significantly related to the composition of the segments assessed by DXA and the authors concluded that segmental BIA has potential in children for assessing limb composition.

Additionally, quantifying both FM and SMMa values allows for the determination of the muscle-to-fat ratio and the comparison of this ratio between individuals and groups. The rationale underlying this measure is that these two tissues have opposing effects on insulin sensitivity and energy disposal, and the balance between them may more accurately predict the risk for metabolic disease beyond the capability of BMI (15). Thus having both a low SMMa and high FM and hence a muscle-to-fat ratio towards the extreme low end of the distribution may compound the risk for metabolic disease beyond that of having excess FM alone. Theory would predict that this ratio could perform better than BMI in childhood as a measure of future metabolic risk although this remains to be tested.

In this study, we used the SMMa results from a bioimpedance segmental body composition analyser to develop a range of reference centile curves in Caucasian children aged 5–18 years in the UK. These curves may be used to assess children’s SMMa in both clinical and epidemiology settings and to identify those with abnormally low SMM. Additionally, in this sample, muscle-to-fat ratio was examined in relation to BMI for age and gender with an additional aim to define the lower limit of normal for muscle-to-fat ratio.

Methods and procedures

Subjects

The data used in this study was drawn from the same study population of UK schoolchildren previously used to develop the BIA-derived percentage body fat centile curves (12). The schools and colleges were located in Hertfordshire, Cambridgeshire and West London. Details of the samples and measurement procedure have been previously reported (12). For that study, we proposed that the sample selected should reflect, as far as possible, the UK1990 growth reference population and so schools from a more affluent background were intentionally targeted in the expectation of finding obesity rates lower than the national levels at that time, which
proved to be the case. Measurements were conducted between July 2003 and June 2004. Only children for whom parental consent was obtained were measured in this study. Data on date of birth, gender and ethnicity were collected together with anthropometry. Measurements were conducted at various times throughout the school day with no constraints imposed on prior meals, drinks or exercise patterns; a situation that would pertain in a clinical setting. Children were individually coded and the data anonymized. The analyses were based on 1985 Caucasian children (1116 boys and 869 girls) aged between 5.0 and 18.8 years. Out of this total sample, SMMa data were available for 1013 boys and 795 girls.

Anthropometric and body composition measurements

Measurements were conducted on school premises by two field workers. Height was measured to the nearest 0.1 cm with a portable stadiometer (Seca, Marsden, UK) with children standing in bare feet. Body mass and predicted body composition was measured using the Tanita BC-418MA single frequency (50 Hz) Segmental Body Composition Analyser (Tanita Corporation, Tokyo, Japan) with correction for light indoor clothing. The measurement procedure required the subject to stand in bare feet on the analyser and to hold a pair of handgrips, one in each hand. The BIA component of the measurements took approximately 30 s per subject. BMI was calculated as weight (kg)/height² (m). As the BIA monitor used for this study provided separate measures of FM, FFM and predicted SMM in the limbs and trunk, a sum of the SMM in the four limbs (appendicular skeletal muscle mass, SMMa) was used to construct the centile curves. The rationale underlying this decision was that SMMa accounts for more than 75% of whole body SMM in adults (16). It is the major fraction of whole body SMM involved in ambulation and physical activities and is likely to be the modifiable fraction of whole body SMM. The prediction equations used in this model are based on bioimpedance, weight, height and age and were derived from calibration studies against whole-body DXA. For limb SMM prediction, segmental electrical measurements (resistance, reactance and impedance) were obtained and appendicular lean soft tissue (mainly skeletal muscle) predictive equations were derived. The impedance instrument used in this study has been validated against DXA in mixed populations of children and adults and found to be superior to previous BIA methods (17). In that study, DXA-derived SMM was not significantly different from, and highly correlated with BC-418 estimates \( r = 0.96, \; P < 0.001 \). A paediatric validation of the BC418MA model against DXA and air-displacement plethysmography (BodPod Life Measurement, Inc. Concord, CA, USA) has also been performed (18). Again results were highly correlated with DXA \( r = 0.91, \) standard error of the estimate = 4.46%) and mean values did not differ significantly. In the current study, the within-day coefficient of variation for the sum of limb SMM was <1%, similar to that previously reported (17).

Ethics approval

This study was approved by the London Metropolitan University Ethics Committee.

Statistical analysis, centile curves and muscle to fat ratio

Descriptive statistics were calculated for anthropometric measures and expressed as mean ± standard deviation (SD). Smoothed centile curves for SMMa were constructed for boys and girls separately using the LMS method (19) which summarizes the data in terms of three smooth age-specific curves, namely L (lambda), M (mu) and S (sigma). The M and S curves correspond to the median and coefficient of variation of SMMa at each age whereas the L curve allows for the age dependent skewness in the distribution. For the construction of the centile curves, data were imported into the LMS software (version 1.25) and the L, M and S curves estimated. Seven centile curves were calculated, from the second to the 98th, spaced two-thirds of an SD score apart, in the layout used in other British growth reference charts (20). Curves were produced to reflect SMMa in three formats, namely, absolute SMMa (kg), SMMa as a percentage of total body mass (%SMMa) and SMMa as a percentage of FFM (SMMa/FFM (kg) × 100). For comparative purposes, centile curves for %FFM were also constructed. In the construction of the SMMa centiles, no other data were excluded with the exception of the 177 children where SMM was not recorded at the time of measurement. Data checking was performed both manually and statistically, with outliers for the measured and derived variables identified by z-scores and cross-checked against the original data collection sheets.

Muscle-to-fat ratio was derived by dividing SMMa (kg) by FM (kg) and expressed as histograms for boys and girls separately. Cases were then divided into two age ranges – 5–10 years and 10–18 years.
and BMI z-score calculated using the UK 1990 BMI reference data (10). For each age range, in boys and girls separately, cases were divided into fifths of BMI z-score and the mean and SD of muscle-to-fat ratio within each fifth calculated. A muscle-to-fat ratio cut-off equating to \(-2\)SD for the middle fifth was determined and the proportion of cases falling below the cut-off was compared between groups. One case with a muscle-to-fat ratio of 6.4 was excluded from the analysis in boys as it was considered an extreme outlier. Statistical analyses were performed using SPSS v 18. Statistical significance was set at \(P < 0.05\).

Results

Table 1 shows the descriptive statistics for the sample presented in narrow ages ranges. Figures 1–4 illustrate the %FFM, SMMa (kg), %SMMa and %SMMa/FMM centile curves respectively, for boys and girls, with the tabulated data listed in Tables as supplementary files. In each chart, the curves represent the 2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles.

For %FFM (Table S1), the curves reflect the reciprocal of %FM previously published (12). The 50th centile for %FFM remains relatively flat in boys, varying between 82 and 85% of body weight across the age range, reaching a nadir at age 11 years – the point at which variability is greatest, possibly due to variability in the timing of initiation of the pubertal phase of growth and anatomical remodelling. For girls, the 50th centile equates to a lower %FFM compared with boys and declines with age until around age 11 years (the mean age at which puberty commences), continuing to decrease at a slower rate up to age 18 years. At this age, the median %FFM equates to 75% of body weight, compared with 85% for boys.

SMMa (kg), %SMMa and %SMMa/FMM show different age-related patterns compared with %FFM. In boys and girls, SMMa (kg) increases with age, with the 50th centile increasing from 5.1 kg to 25.6 kg in boys and from 5.1 kg to 18.2 kg in girls between ages 5 and 18 years (Fig. 2, Table S2). In addition, age-related variability in SMMa (kg) increases in boys across the age spectrum, whereas in girls, variability increases to peak at around age 13 years after which

<table>
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<th>n</th>
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<th>Weight (kg)</th>
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<th>FM (kg)</th>
<th>SMMa (kg)</th>
<th>SMMa (%)</th>
<th>SMMa/FMM (%)</th>
<th>MFR</th>
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</table>

Figures in parentheses indicate the number of children in each age range where data on skeletal muscle mass (SMMa) were available. BMI, body mass index; FFM, fat-free mass; FM, fat mass; SMMa, appendicular skeletal muscle mass; MFR, muscle:fat ratio.
it decreases. In boys, the 50th centile for %SMMa increases from 27% at age 5 years up to around 35% at age 15 years, remaining relatively flat thereafter. In girls, the 50th centile changes somewhat less with age, with the curves remaining relatively flat between ages 5 and 11 years (at around 28% SMMa) and then increasing slightly until age 18 years, with %SMMa peaking at around 31% (Fig. 3, Table S3). At this age, boys have 13% more SMMa than girls. The age-related variability in the %SMMa curves remains highly consistent until age 16 years in boys and across the whole age range in girls.

Figure 4 (Table S4) shows that the 50th centile for %SMMa/FFM in boys increases between ages 5 and 15 years from 32 to 42% with the variance being greatest at age 5 years and then decreasing. Between ages 15 and 18 years, the 50th centile line flattens, with the variance decreasing even further, such that between the 2nd and 98th centiles, the range spans only between 40 and 44%. In girls, %SMMa/FFM curves share some of the characteristics of those in boys, increasing with age, with the variance continually decreasing with age.

**Muscle-to-fat ratio**

Figure 5 shows the histograms of muscle-to-fat ratio distribution for boys and girls (all ages combined). In boys, the mean (SD) muscle-to-fat ratio was 1.99 (0.60) and ranged between 0.69 and 4.84. The equivalent data for girls was 1.38 (0.40), (range 0.49–3.22). Thus at least a threefold range in muscle-to-fat ratio was observed. Pearson’s correlation coefficient revealed a significant positive relationship between age and muscle-to-fat ratio in boys ($r = 0.300$, $P < 0.01$) and a significant negative correlation in girls ($r = -0.268$, $P < 0.01$). Table 2 shows the mean (SD) muscle-to-fat ratio within each fifth of BMI z-score for boys and girls separately. In all groups, mean muscle-to-fat ratio decreased with increasing BMI z-score. The SD was noticeably larger in older, leaner boys.
We have defined the lower limit of normal for muscle-to-fat ratio as the mean minus 2SDs for children in the middle fifth of the BMI range. These approximate to 1.25 for boys in both age groups and 1.10 in the younger girls and 0.80 in the older girls. Table 2 also lists the proportions with muscle-to-fat ratio below these cut-offs. These rise to 38.4% (boys) and 63.8% (girls) in the highest BMI groups for the younger age children and 43.6% (boys) and 26.9% (girls) in the older children.

**Discussion**

In this study, we set out to produce centile curves for fat-free and skeletal muscle components of body composition in children and youths and to determine the muscle-to-fat ratio and how this varies across BMI for age and gender. The charts illustrate the changes and variations in the proportions of the body compartments across human growth, and used in conjunction with previously published body fat curves based upon the same population, can provide users with a more detailed assessment of body composition against a reference population than the equivalent BMI charts.

These charts reveal clear gender specific changes accompanying growth. Firstly, %FFM decreases with age in girls – a consequence of the normal ontogenic increase in the proportion of fat, but perhaps noteworthy for the fact that the greatest decrease occurs before, rather than across the pubertal stage; a change that may contribute to the initiation of puberty (21). In boys %FFM is relatively stable across childhood and early teens, at which point it starts to increase, a likely reflection of the testosterone driven increase in lean and mineral tissues. Additionally, the charts reveal that, as expected, SMMa (kg) increases with age, with a noticeable spurt in boys around the pubertal stage which is either absent or less obvious in girls. These charts also reveal that %SMMa increases in boys up to age 15 years, at which point it remains stable as a proportion of whole body mass.
Figure 5  a, b. Histograms of muscle-to-fat ratio in boys and girls. Data as in Figure 2.
up to age 18 years. In girls, an opposite pattern is observed with %SMMa remaining stable up until the pubertal stage, at which point it starts to rise. %SMMa is consistently lower in girls, again a result of their higher absolute and proportional body fatness. This study does not provide information on the determinants of these differences which may include differences in diet or physical activity habits.

These centile charts also reveal differences in age- and gender-related variability in the measure, depending on the specific component of FFM. The greatest age-related variability is seen in the %FFM which is to be expected since it reflects the muscle, organ and skeletal components and to an extent FM, since %FMM is the reciprocal of %FM. Expressing SMMa in absolute terms (kg) reveals a positive relationship between age and variability again an expected finding when the mass of this tissue increases with age. However, when expressed as a percentage of body mass, age-related variability in SMMa is consistent across the age spectrum in boys until around age 16 years when variability narrows, a characteristic which is not seen in girls. Expressing SMMa as a percentage of FFM across the age range removes the influence of body fatness and allows clearer consideration of both gender differences and the variation in SMMa in relation to FFM with increasing age. These charts reveal similarities between boys and girls in this variable both in absolute terms and across the age range. That both the change and variance decrease with increasing age suggests a previously undescribed tendency towards stabilization and standardization of the SMMa:FFM ratio in late adolescence and early adulthood. A markedly reduced variance would be predicted as children emerge from puberty at variable ages, but the fact that it is markedly lower than before the pubertal stage, suggests a biological mechanism that is seeking to establish a rather standard ratio between SMM and the other components of FFM.

These are the first, and to date, only BIA-derived curves produced to illustrate gender and age-related variation in %FFM and SMMa in children and youths, thus comparisons with similar studies cannot be made. However, both whole body and SMMa have been quantified in both adults and children using reference laboratory methods (7,8). One recent study by Wang et al. recruited a paediatric sample with a similar age range and mean age to our study, but both the mean weight and height were higher in their sample, thus making SMMa comparisons less straightforward (9). With this in mind, mean SMMa in this study represented 77% in boys and 81% in girls of the whole body SMM from the Wang et al. study, whereas in adults a SMMa figure of 74% of whole body SMM has been reported (7). Additionally, a recent Canadian study has presented age- and gender-specific whole-body SMM reference curves derived from DXA-generated SMMa, albeit on a much smaller (n, 140) sample population (22). Again, direct comparison is not straightforward as whole-body SMM rather than SMMa curves are presented and the ethnicity of the sample is not stated. Generally, the Canadian curves are more sigmoidal in shape, nevertheless our mean SMMa (kg) values approximate 85% (boys) and 92% (girls) at age 5

### Table 2

<table>
<thead>
<tr>
<th>Fifth</th>
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<th></th>
<th>Girls</th>
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<td>MFR</td>
<td>% below cut-off*</td>
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<td>−0.556 (0.15)</td>
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<td>69</td>
<td>1.744 (0.53)</td>
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<td>10–18 years</td>
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<tr>
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<td>2.60 (0.75)</td>
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<td>91</td>
<td>−1.258 (0.52)</td>
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<td>−0.412 (0.14)</td>
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<tr>
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<td>0.205 (0.16)</td>
<td>2.25 (0.51)</td>
<td>0.0</td>
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<td>0.029 (0.12)</td>
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<td>4</td>
<td>116</td>
<td>0.812 (0.19)</td>
<td>2.04 (0.49)</td>
<td>2.6</td>
<td>92</td>
<td>0.552 (0.18)</td>
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<tr>
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<td>117</td>
<td>1.772 (0.46)</td>
<td>1.33 (0.37)</td>
<td>43.6</td>
<td>93</td>
<td>1.557 (0.49)</td>
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*MFR cut-off = 1.25 for boys.
†MFR cut-offs = 1.1 for girls 5–10 years and 0.8 for girls 10–18 years.
MFR, muscle:fat ratio.
years and 73% (boys) and 82% (girls) at age 15 years of their whole-body SMM (kg) values.

As we previously reported, any anthropometric reference curves need to be based on a representative sample of the population and fixed in time given the rapid anthropometric transitions that are occurring in affluent nations (23). We proposed that the sample selected for our study should reflect, as far as possible, the UK1990 growth reference population. Examination of the z-scores for height and weight indicated that the children in our sample were slightly taller and heavier than UK1990, but had mean BMI z-score close to zero and an SD close to the expected 1.0 thus giving confidence in its appropriateness as a reference population comparable to UK 1990 (12).

We propose to make the SMMa charts available in the same way as the body fat charts, and add them to the growing suite of assessment tools available for research studies as well as finding potential use in the clinical tracking of anthropometry and body composition. The software allowing individual measurements to be converted to z-scores will also be produced but it should be reiterated that at present these charts are only applicable to measurements conducted on Caucasian children using the Tanita BC418MA Segmental Body Composition Analyser. However, there are emerging studies in the literature where additional centile charts are being developed based on the same BIA system, for example in Hong Kong (24) and Turkish children (25). It may be possible with appropriate cross-calibration that other Tanita models and other makes of bioimpedance analysers could be used in conjunction with these charts and we intend to develop similar charts for use with other ethnic groups. It should be noted, however, that the chemical maturation of the FFM has not been accounted for in the BIA equations. It has been reported that the hydration of FFM declines from about 76% at age 6 years to 73% at age 17 years (26), whereas the Tanita equations assume 73% throughout. Proportionately, this could suggest that hydration of the SMM might be overestimated by about 4% in the youngest children. However, we believe this potential 4% bias is acceptable since it is proposed that these curves act as references against which to judge the SMM of individuals, groups or populations and a 4% bias at younger ages would make little difference to the shapes of the curves. Furthermore, this potential bias would have little impact on the ability of our suggested muscle-to-fat ratio to discriminate between children based on this ‘sarcopenic’ index.

This study also examined the muscle-to-fat ratio in relation to gender, age and BMI. Calculation of the muscle-to-fat ratio surprisingly revealed a very wide range; from 0.69 to 4.84 in boys (with a single outlier at 6.4) and from 0.49 to 3.22 in girls. Figure 5 shows that even excluding outliers there was a greater than fourfold range in boys and greater than threefold in girls. Given that (excess) fat and muscle generally have reciprocal influences on glucose sensitivity (27), it is reasonable to speculate that the muscle-to-fat ratio would be a better predictor of metabolic health than BMI and that, for example, a boy with a muscle-to-fat ratio of only 0.75 would have greater difficulty in maintaining glucose homeostasis than a boy with a muscle-to-fat ratio of 3.0. This speculation requires formal testing. It should be emphasized that the relationships between muscle-to-fat ratio and metabolic health may be non-linear since gluteofemoral adipose tissue has been shown to protect metabolic health (28) and the extreme absence of body fat, as in lipodystrophy, is associated with insulin resistance (27). In this respect, the boys in Fig. 5a with a muscle-to-fat ratio over 4.0 (plus the excluded subject with a muscle-to-fat ratio of 6.4) and the girls in Fig. 5b with a muscle-to-fat ratio greater than 2.5 might benefit from metabolic/clinical investigation.

If the muscle-to-fat ratio is shown to be a good index of metabolic health it could facilitate the sub-classification of overweight and obese children into ‘high-’ and ‘low-risk’ based on their muscle-to-fat ratio. For example children within the high BMI-for-age categories could comprise a mixture of those with a ‘healthy’ muscle-to-fat ratio while others could be displaying the early signs of sarcopenic obesity (29). It is noteworthy that even in the highest fifths of BMI, 56 and 61% of boys and 36 and 73% of girls have muscle-to-fat ratios classified as within the normal range calculated as the mean minus 2 SDs from the middle fifth. Given the sensitivities surrounding the monitoring of body weight and obesity in children, it is particularly important to be able to identity high-BMI children who are not inappropriately overly fat. It is proposed, therefore, that these charts are used in a clinical setting to track skeletal muscle mass within individuals in an analogous way to current weight and height charts. They will be able to identify individuals at the extremes of skeletal muscle mass for age and gender and will also reduce misclassification of muscular children who are rated as overweight or obese by BMI. Additionally, using BIA to assess either the FFM/FM ratio or the muscle-to-fat ratio could also represent an important advance in survey methodology. This
measure could be useful in the follow up of individuals deemed at risk and this requires further prospective testing.

In conclusion, this study has added SMMa to the suite of charts available for assessing growth and body composition across childhood and adolescence. Muscle-to-fat ratio has been described which could show potential as an improved measure of metabolic risk although further investigation is required to verify this suggestion.

**Conflict of interest statement**

HDM has received research funding from Tanita UK (this study). AMP and SAJ have received past research funding from Tanita UK and are members of the Tanita Medical Advisory Board.

**Authors contribution**

AMP, SAJ and HDM conceived the ideas. DSR and HDM collected and managed the data. HDM analysed the data and generated the curves and muscle-fat ratios. All authors were involved in writing the paper and had final approval of the submitted and published versions.

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**References**


Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher’s web-site:

**Table S1.** Tabulated % fat-free mass centile values by exact age.

**Table S2.** Tabulated skeletal muscle mass (kg) centile values by exact age.

**Table S3.** Tabulated % skeletal muscle mass centile values by exact age.

**Table S4.** Tabulated % skeletal muscle mass/fat-free mass centile values by exact age.