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PEDIATRIC HIGHLIGHT

Body fat reference curves for children

HD McCarthy[1], TJ Cole[2], T Fry[3], SA Jebb[4] and AM Prentice[5]

[1]Institute for Health Research & Policy, London Metropolitan University, London, UK; [2]Centre for Paediatric Epidemiology and Biostatistics, Institute of Child Health, London, UK; [3]Child Growth Foundation, 2 Mayfield Avenue, London, UK; [4]MRC Human Nutrition Research, Elsie Widdowson Laboratory, Cambridge, UK and [5]MRC International Nutrition Group, London School of Hygiene and Tropical Medicine, London, UK

Objective: To refine the diagnosis of childhood obesity by creating new sex-specific centile curves for body fat and to base these references on a simple and affordable method that could be widely adopted in clinical practice and surveys.
Design: Body fat was measured by bio-impedance in 1985 Caucasian children aged 5–18 years from schools in Southern England. Smoothed centile charts were derived using the LMS method.
Results: The new body fat curves reflect the known differences in the development of adiposity between boys and girls. The curves are similar by sex until puberty but then diverge markedly, with males proportionately decreasing body fat and females continuing to gain. These sex differences are not revealed by existing curves based on body mass index. We present charts in which cutoffs to define regions of 'underfat', 'normal', 'overfat' and 'obese' are set at the 2nd, 85th and 95th centiles. These have been designed to yield similar proportions of overweight/overfat and obese children to the IOTF body mass index cutoffs.
Conclusions: Direct assessment of adiposity, the component of overweight that leads to pathology, represents a significant advance over body mass index. Our new charts will be published by the Child Growth Foundation for clinical monitoring of body fat, along with the software to convert individual measurements to *Z*-scores.
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Keywords: children; centiles; body fatness; bioelectrical impedance; Caucasian

Introduction

The obesity epidemic, at one time confined to adults, has now penetrated the paediatric age range and shows every sign of a rapid escalation.[1,2] This has led to calls for better assessment tools both for longitudinal and cross-sectional surveillance of populations, and for clinical management of individuals.[1,3]

Body mass index (weight (kg)/height^2 (m)) is widely used to assess overweight and obesity, and standard cutoff values are now widely accepted for adults. In children BMI changes considerably during growth and development. This necessitates the use of centile curves with variable cutoff values for different ages, for example, the British 1990 reference[4] published by the Child Growth Foundation, the US Centers for Disease Control (CDC) 2000 charts,[5] and the curves currently adopted by the International Obesity Task Force (IOTF).[6]

Although body mass index is simple to measure and has been a valuable tool in monitoring trends in obesity, it also has numerous disadvantages.[7] Principally, it does not distinguish between increased mass in the form of fat, lean tissue or bone, and hence can lead to significant misclassification. Since the pathology associated with obesity is driven by the excess fat mass[8] the ideal monitoring tool should directly assess adiposity. Many tools are available to do this but are complex, time consuming and expensive. Considerable research has gone into developing bio-impedance monitors that can distinguish between lean and fat tissue on the basis of their differential conductance and impedance characteristics.[9] These techniques are slightly less accurate than the more sophisticated research tools, but offer an important practical advantage in being simple and cheap to use.

We used the total body fat results from a bioimpedance segmental body composition analyser to develop reference centile curves in 1985 Caucasian children aged 5–18 years in the UK. These curves may be used to assess children's adiposity in both clinical and survey settings.

Correspondence: Dr D McCarthy, Institute of Health Research & Policy, London Metropolitan University, Holloway Road, London N7 8DB, UK.
E-mail: d.mccarthy@londonmet.ac.uk
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Subjects and methods

Subjects

The study population consisted of an opportunistic sample of school children, recruited into the study following initial contact with the school/college. A total of 21 schools and colleges located in Hertfordshire, Cambridgeshire and West London agreed to participate in the survey. Parents/carers were sent a letter explaining the aims of the study and requesting permission for their child to take part. Only children for whom signed parental consent was obtained were measured in this study. No information about current medication use or whether the child was following any weight management diet was collected. The sample is not therefore biased by such exclusions. Data on date of birth, gender and ethnicity were collected together with anthropometry. Children were individually coded and the data anonymised. The analysis was restricted to 1985 Caucasian children (1116 boys and 869 girls) aged between 5.0 and 18.5 years.

Anthropometric and body fat 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 total body fatness were measured using the Tanita BC-418MA 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 bio-impedance component of the measurements took approximately 30 s per subject. Body mass index was calculated as weight (kg)/height^2 (m). Although the body fat monitor used for this study provides separate measures of fat in the trunk and limbs, only the whole-body percentage fat was used to construct the centiles. The prediction equations used in this model are based on bio-impedance, weight, height and age and were derived from calibration studies against whole-body dual X-ray absorptiometry (DXA). The s.e. of the estimate for boys was 2.7% and for girls was 2.8% body fat (data provided by manufacturer). The impedance scales 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.[10] More recently a pediatric validation of the BC-418MA model against DXA and air-displacement plethysmography (BodPod) has been performed.[11] In samples of 45 boys (age 11.0±3.6 year) and 34 girls (age 11.0±3.0 year) results were highly correlated with DXA (r=0.91, SEE=4.46%) and mean values did not differ significantly. In the current study, the within-day coefficient of variation for percentage body fat was 1.3%.

Ethical approval

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

Statistical analysis and centile curves

Centile curves for body fat percentage were constructed for boys and girls separately using the LMS method, which summarises 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 body fat percentage at each age whereas the L curve allows for the age dependent skewness in the distribution of body fat percentage. For the construction of the percentile 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 2nd to the 98th, spaced two-thirds of an s.d. score apart, in the format used for other British growth reference charts.[12] We then selected the 2nd centile to define the upper limit of underfat, and the 85th and 95th centiles to define the lower limits of overfat and obese. The rationale behind these cutoffs is discussed below.

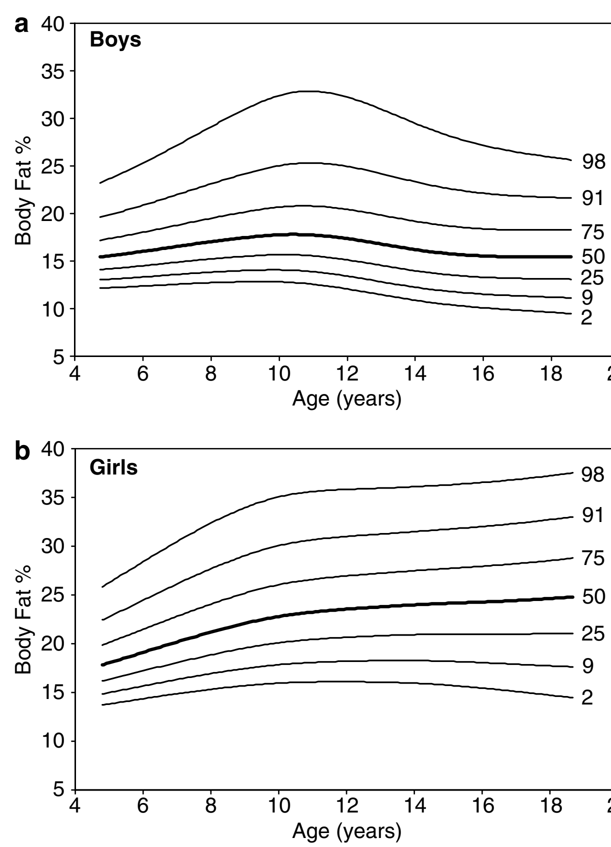

Figure 1 Body fat centile curves for Caucasian boys and girls. Data from 1116 boys and 869 girls aged 5–18 years smoothed by the LMS method. Numbers on right-hand side represent centiles.

Table 1 Tabulated body fat % centile values by exact age

	Centile								
Years	*2*	*9*	*25*	*50*	*75*	*85*	*91*	*95*	*98*
Boys									
5.0	12.2	13.1	14.2	15.6	17.4	18.6	19.8	21.4	23.6
6.0	12.4	13.3	14.5	16.0	18.0	19.5	20.9	22.7	25.3
7.0	12.6	13.6	14.9	16.5	18.8	20.4	22.0	24.1	27.2
8.0	12.7	13.8	15.2	17.0	19.5	21.3	23.1	25.5	29.1
9.0	12.8	14.0	15.5	17.5	21.2	22.2	24.2	26.8	31.0
10.0	12.8	14.1	15.7	17.8	20.7	22.8	25.0	27.9	32.4
11.0	12.6	13.9	15.4	17.7	20.8	23.0	25.3	28.3	32.9
12.0	12.1	13.4	15.1	17.4	20.4	22.7	25.0	27.9	32.2
13.0	11.5	12.8	14.5	16.8	19.8	22.0	24.2	27.0	31.0
14.0	10.9	12.3	14.0	16.2	19.2	21.3	23.3	25.9	29.5
15.0	10.4	11.8	13.6	15.8	18.7	20.7	22.6	25.0	28.2
16.0	10.1	11.5	13.3	15.5	18.4	20.3	22.1	24.3	27.2
17.0	9.8	11.3	13.1	15.4	18.3	20.1	21.8	23.9	26.5
18.0	9.6	11.2	13.1	15.4	18.3	20.1	21.7	23.6	25.9
Girls									
5.0	13.8	15.0	16.4	18.0	20.1	21.5	22.8	24.3	26.3
6.0	14.4	15.7	17.2	19.1	21.5	23.0	24.5	26.2	28.4
7.0	14.9	16.3	18.1	20.2	22.8	24.5	26.1	28.0	30.5
8.0	15.3	16.9	18.9	21.2	24.1	26.0	27.7	29.7	32.4
9.0	15.7	17.5	19.6	22.1	25.2	27.2	29.0	31.2	33.9
10.0	16.0	17.9	20.1	22.8	26.0	28.2	30.1	32.2	35.0
11.0	16.1	18.1	20.4	23.3	26.6	28.8	30.7	32.8	35.6
12.0	16.1	18.2	20.7	23.5	27.0	29.1	31.0	33.1	35.8
13.0	16.1	18.3	20.8	23.8	27.2	29.4	31.2	33.3	25.9
14.0	16.0	18.3	20.9	24.0	27.5	29.6	31.5	33.6	36.1
15.0	15.7	18.2	21.0	24.1	27.7	29.9	31.7	33.8	36.3
16.0	15.5	18.1	21.0	24.3	27.9	30.1	32.0	34.1	36.5
17.0	15.1	17.9	21.0	24.4	28.2	30.4	32.3	34.4	36.8
18.0	14.7	17.7	21.0	24.6	28.5	30.8	32.7	34.8	37.2

The 2nd, 85th and 95th centiles define the cutoffs for underfat, overfat and obese.

Results

Preliminary analysis of the children in this study showed that they were generally similar in height and BMI compared with the UK 1990 and US CDC 2000 references. Figure 1 illustrates the full set of centile curves for the boys and girls. The tabulated data are listed in Table 1.

The boys show a relatively flat 50th centile varying between 15 and 18% body fat over the entire age range, with a peak at age 11 year. Variability increases up to age 11 year with a marked increase in positive skewness. Both skewness and variability fall after age 11 year, but the lower centiles diverge slightly from the 50th centile.

The girls centiles show a similar pattern to the boys up to age 10 year but are then strikingly different in shape. The 50th centile continues to rise slightly while the other centiles diverge from the 50th centile.

At age 18 year the girls have proportionately 60% more body fat than the boys; the median percent body fat values are 24.6 and 15.4%, respectively. The 98th centiles are 37.2 and 25.9%, and the 2nd centiles 14.7 and 9.6%.

In order to define clinically and epidemiologically useful cutoffs that are broadly consistent with the body mass index cutoffs currently adopted by the International Obesity Task Force (IOTF) we applied the IOTF cutoffs to the current data set and selected the nearest body fat centile cutoffs. The 85th and 95th centile lines provided a close approximation to the overweight and obese boundaries of the IOTF curves, while the 2nd centile was chosen (fairly arbitrarily) to form the underweight boundary. These centiles are illustrated in Figure 2 and tabulated in the Table 1. The new boundaries define underfat, normal, overfat and obese children.

Discussion

The shapes of the body fat curves produced by this study match the expected changes in fat patterning during human growth.[13] Following an early decrease in body fat during infancy (not seen in these data since they start only at age of 5 years), body fat increases until puberty. At puberty sex hormones induce a pronounced sexual dimorphism: males gain proportionately more muscle and lean tissue compared to fat, and females lay down fat as a natural part of the ontogeny of their sexual and reproductive physiology. Note that these normal anatomical differences are not reflected in

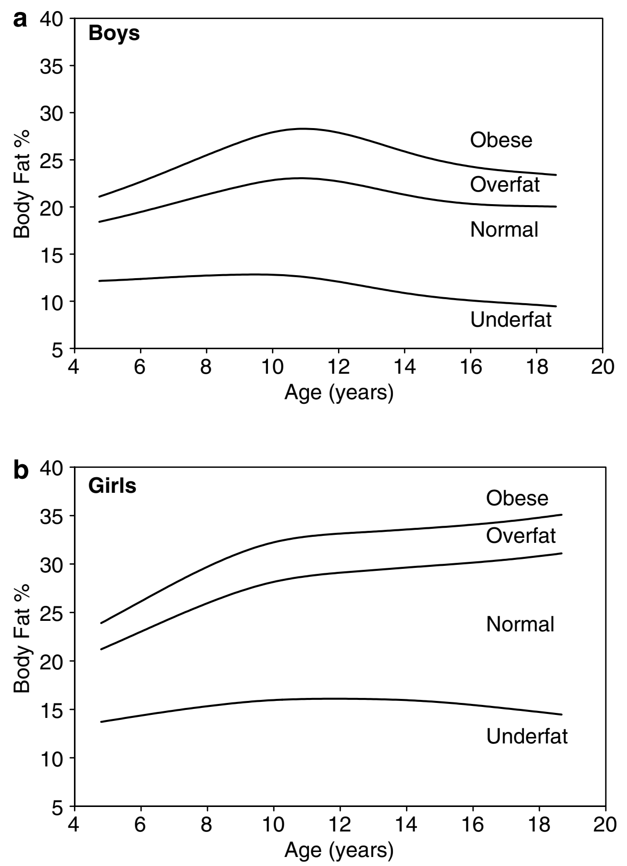

Figure 2 Recommended cutoffs for defining underfat, normal, overfat and obese children. Data as in Figure 1 Charts apply to Caucasian children.

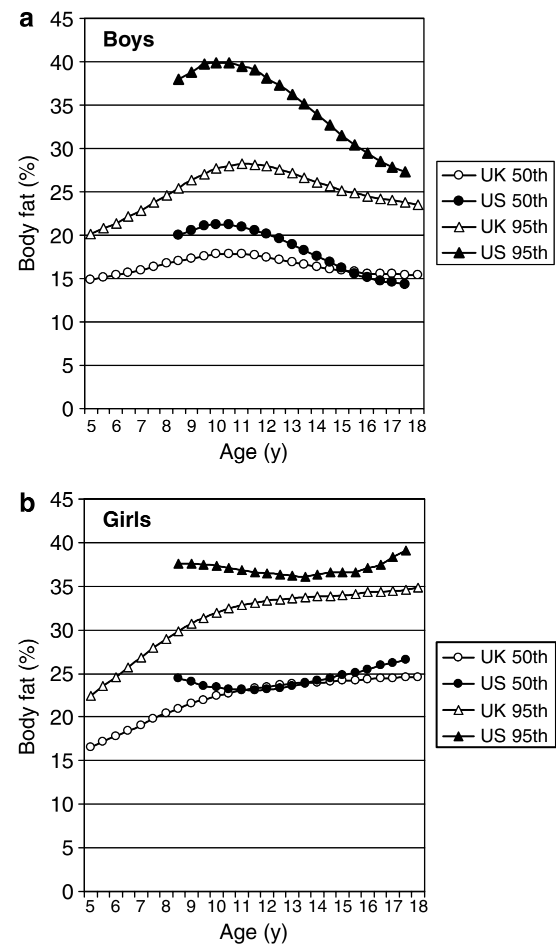

Figure 3 Comparison of current reference curves for body fat against data from a similar sample from the United States. US data from Mueller *et al.*[14].

the corresponding body mass index curves, which show remarkably similar patterns for boys and girls.[4]

Body fat curves have recently been published from Project Heartbeat in the United States using an alternative bio-impedance system (RJL Systems, model not stated).[14] These were derived from a smaller sample (278 boys, 263 girls) and over a narrower age range (8.5–17.5 year). The 50th centile curves from the two samples agree quite closely with a maximum difference of 3.4% body fat in boys and 3.5% in girls (see Figure 3). However, the 85th and 95th centiles from the US data are much higher in the age range 8–12 years with a maximum deviation of 12.7% body fat boys (US boys 95th centile = 39.7% and UK boys 95th centile = 27.0% at 9.5 years). This may reflect imprecision in estimating the 95th centile from the smaller US sample, but more likely reflects a greater prevalence of obesity in the US.

The fact that body mass index represents only a crude proxy for body fat and may produce a significant level of misclassification is universally accepted but widely ignored. This is because, in the absence of alternative measures, the advantages of body mass index have outweighed its disadvantages.[15] However, bio-impedance offers the opportunity to move beyond body mass index.[7] Its advantages are that it is relatively inexpensive, portable, simple and rapid to use. Its disadvantages are that it is less accurate than more sophisticated methods.

We propose the body fat centile curves presented here as an alternative or addition to using body mass index curves. The chief merit of the new curves is that they assess adipose tissue mass, the component of excess weight that is associated with comorbidities.[8] They will also reduce misclassification in large-framed and/or muscular children who are rated as overweight or obese by body mass index. Additionally the new curves will help focus medical attention on excess adiposity as distinct from overweight. To further emphasise this distinction we propose that the four categories identified in the proposed clinical cutoff charts in Figure 2 should be termed 'underfat', 'normal', 'overfat' and 'obese'.

As with all anthropometric reference curves it is necessary to use a representative sample of the wider population of interest. Geographical, ethnic, socio-economic and nutritional considerations have always been important in designing the sampling frame. In the case of body fat, timing has also become a vital consideration in the light of the rapid secular increase in obesity. We, therefore, reasoned that it would be optimal to try to match our sample with the body mass index charts, and especially the British 1990 growth reference sample. This would avoid the confusion that would arise if, in future analyses, the existing Child Growth Foundation or IOTF body mass index charts and our new body fat charts had generated widely divergent estimates of overweight/overfat and obese children. To this end, we intentionally approached schools in more affluent areas in the expectation of finding obesity rates lower than the current national average[16] and close to the 1990 sample. This strategy was successful. The children in our new sample were slightly taller (+0.41 *Z*-scores) and slightly heavier (+0.14 *Z*-scores) than British 1990. However, their BMI *Z*-score was close to zero (−0.13 *Z*-scores) with a s.d. of 1.19 (i.e., close to the expected 1.00).

Although we believe that reference curves based on actual body fat are an advance over other measures, the definition of cutoffs shares a common problem with all previous charts; namely that we lack clinical correlates on which to base such cutoffs. There is an urgent need for large-scale surveys that could relate body fat in children (using curves such as those presented here) and future risk factors for obesity-related ill health.

The body fat charts will be published by the Child Growth Foundation to add to their series on weight, height, waist and body mass index (Available from Harlow Printing, Maxwell St, South Shields, NE33 4PU. Tel: +0191 455 4286. E-mail: sales@harlowprinting.co.uk.). They can be used in a clinical setting to track body fat within individuals in an exactly analogous way to current weight and height charts. Similarly the Child Growth Foundation's anthropometry software to convert individual measurements to *Z*-scores has been extended to include percent body fat. It is important to emphasise that these charts were derived using the BC-418MA Segmental Body Composition Analyser. The charts should not be used in conjunction with other makes and models of bio-impedance monitors until cross-calibration studies have been performed in children. Finally, these curves should only be used for Caucasian children. We hope to develop additional sets for Afro-Caribbean and Asian children in the future.

Acknowledgements

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Conflict of interest

David McCarthy 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.

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