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Defining Childhood Obesity

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General Definition of Obesity

Obesity is generally defined as the abnormal or excessive accumulation of fat in adipose tissue to the extent that health may be impaired [1]. Measuring the level of adipose tissue and determining when it is likely to affect health is not an easy task. Quantification of adipose tissue mass can be achieved by a number of laboratory methods including underwater body density measurement and body fat content estimated by the dual-energy X-ray absorptiometer (DEXA). In addition, the development of new techniques, such as magnetic resonance imaging (MRI) and computed tomography (CT), has provided researchers with opportunities to describe human adiposity in more detail [2, 3]. However, most of these methods require costly equipment meaning that their use is limited to clinical research setting.

In large-scale population surveys and clinical/public health screening, an index of body weight adjusted for stature is commonly used as a surrogate for body fat content [4, 5]. These indices are defined as different combinations of weight and height, such as weight divided by height or are defined as weight expressed as a percentage of mean weight for a given height and sex [6]. The most widely used is Quetelet's index, better known as body mass index (BMI), which is body weight (kg) divided by height squared (m^2). This index has been shown to correlate weakly with height and strongly with body fatness in adults [4, 7].

Although the correlation between BMI and body fat adjusted for height is high (r = 0.82–0.91) in adults [8], BMI fails to distinguish between lean body mass and fat. Thus, the relationship between BMI and body fatness varies according to body composition and proportions [9]. For instance, the percentage of body fat mass is higher in females than in males with a similar BMI.

In addition, body fatness has been shown to vary by age both before adulthood and with ageing. Any age-related change in height has an influence on BMI as well.

Determining the weight status and level of adiposity in children and adolescents is even more problematical. This is a stage of rapid growth and development. During growth in childhood and adolescence, not only does height increase but body composition changes as well, thus classification of obesity according to a single measure is difficult. In addition, international or regional weight status standards for children and adolescents may be less reliable as the age of onset of puberty and its associated physical changes often varies between different countries, ethnic groups or cultures [1].

Methods for Identifying Obesity in Children

In defining obesity in children and adolescents we are attempting to identify those with excessive adiposity. However, the ability to accurately estimate level of body fatness is only one of the criteria necessary for an effective measure of obesity. Power et al. [10] suggest that of equal importance is the simplicity of the measure, the cost, ease of use and acceptability to the subject. It must also be well documented with published reference values. None of the major approaches to defining childhood and adolescent obesity outlined below meets all these criteria.

Anthropometric Measures

Anthropometric measures are the most commonly used method for defining overweight and obesity in children and adolescents. However, to date, there has been no consistency in the way that these have been applied.

Relative Weight for Height and Age

Many countries have developed growth reference charts by performing cross-sectional studies in a large number of children from birth into adulthood. This has allowed the construction of charts that indicate the normal changes in weight and height that would be seen in both girls and boys at different ages. The spread of variation in growth patterns is usually indicated by fitting growth curves and then defining percentiles on these charts. Those whose measurements fall within very low percentiles of weight for age are seen as underweight and those within the top percentiles of weight for age as overweight and obese.

Childhood and adolescent obesity has typically been defined in terms of relative weight for height and age. In this approach, cut-off points for overweight and underweight are defined as a set percentage above or below the standard weight for a given height in the individual's age and sex group.

The standard weight is usually determined as the mean or median determined from a reference distribution for the population.

A variety of cut-off points have been proposed with the most commonly used approach classifies obesity as 120% or more of the standard (median) weight for sex, height and age. Other classification systems use certain percentiles in the reference growth curves to define weight status with the 85th percentile commonly used as the cut-off point for overweight and 97th percentile for obesity. A more sophisticated and precise measure of weight status involves calculating the Z (or standard deviation) score by subtracting the reference value from the measured weight and dividing by the standard deviation of the reference population. A Z score of +2 or more (i.e. 2 SD above the median) is usually taken to indicate obesity. Because this approach provides a comparable measure of weight status which is continuous and not influenced by age and gender it is often used in research projects where means and standard deviations of the relative weight need to be calculated for a group. However, it is difficult to calculate without the assistance of a computer and a more difficult concept for lay people to interpret.

Defining obesity in terms of relative weight for height and age provides a simple assessment process but it has a number of limitations regardless of the way that cut-off points are defined. It is based on the concept that a certain level of deviation from the median or reference population weight defines obesity regardless of whether the median changes. This limits its use in monitoring and surveillance as the reference curves are likely to vary between countries and may change over time within one country. Consequently, this approach does not result in an increase in the prevalence of obesity, although the mean weight in a height, age and sex group of the reference population increases. In addition, it is arbitrary and has not been associated with any objective measure of obesity-related health outcome in children and adolescents.

Body Mass Index for Age

Body Mass index is a ratio of the body weight in kilograms divided by the square of the height in meters. It has been shown to be a good indicator of adiposity in adults and there is a wide body of evidence which links increasing BMI to increased risk of morbidity and mortality in adults.

Although the relationship between BMI and adiposity is not as tight in children as it is in adults it still appears to be a useful tool for identifying overweight and obese children. The correlation between BMI and fat mass determined by DEXA was found to vary widely from 0.5 to 0.85 [11–13]. However, the false-positive rate was very low indicating that whilst it might identify some overweight children as normal weight there is a low likelihood that children would be misclassified as overweight [14]. As with adults, the relationship between BMI and adiposity in children and adolescents will vary in those at the extremes of height and muscularity.

Although BMI for age has been identified as a useful measure of adiposity in children and adolescents its value in defining overweight and obesity has been limited by the lack of standard reference values. Only a small number of countries have defined reference growth charts, which include BMI for age percentiles. Cut-off points are defined in much the same way as they are for relative weight for height for age. Most countries have chosen to nominate the 85th and 95th percentiles of BMI for age and gender to define overweight and obesity, although there is still some support for the use of BMI for age Z scores.

As BMI for age relies on reference growth curves, this definition of overweight and obesity suffers from many of the same limitations as relative weight for height and age. As yet there have been no studies that have demonstrated that BMI for age is associated with the development of immediate and longer-term ill health. In addition, changes in the median and BMI distribution within the reference curves will influence how children and adolescents are defined as obese regardless of their absolute level of fatness.

A workshop organized by the International Obesity Task Force (IOTF) in 1997 concluded that some of these limitations could be overcome by developing a set of BMI percentile curves based on an international reference population and by defining cut-off points in relation to the percentiles that equates to a BMI of 25 kg/m^2 and a BMI of 30 kg/m^2 in adults. In doing so, the cut-off points for overweight and obesity are defined on the basis of a BMI percentile which has been associated with excessive risk of ill health in adulthood rather than being dependent on the median BMI value [15]. This approach was the basis of a set of international cut-off points published by Cole et al. [16], which are discussed later.

Additional Weight-for-Height Ratios

A range of ratios using weight and height, in addition to relative weight and BMI, have been proposed as methods for defining adiposity in children. The ponderal index (also known as Rohrer index) is defined as weight in kg divided by the cube of the height in meters and is sometimes used to define weight status in infants. The conicity index [17], defined as waist circumference/(0.109 $\times$ square root of height/weight), is also occasionally used in young children. These indices are not in common use and reflect relative leg length, body frame size, lean body mass as well as fatness [9].

Skinfold Thickness

Measurement of the skinfold thickness at various sites on the body has been used for many years to indicate both inadequate and excessive adiposity in children. A skinfold thickness measures the amount of subcutaneous fat but an equation developed from the combination of measurements at defined sites provides a reliable estimate of total adiposity [18]. In addition, skinfold measurements taken at just the triceps by trained operators were shown to correlate well with estimates of total adiposity from DEXA in US children [13] and measurements of abdominal skinfolds also correlated highly with estimates of intra-abdominal adiposity obtained from CT or MRI scans [19]. The ratio of subscapular to triceps skinfold thickness has also been shown to be a good predictor of a centralized fat distribution [20].

Skinfold thickness is a cheap and relatively simple measure to perform, although skinfolds may be difficult to be measured in obese subjects. In addition, its reproducibility both for a single observer on the same subject and for different observers vary greatly. Skinfold thickness also appears to vary with race. The lack of growth charts for skinfold thickness or skinfold ratio limits its use for defining childhood obesity and as yet there are no clear associations between skinfold measures and risk of metabolic disease [10].

Waist Circumference

Waist circumference is now accepted as a reasonable guide to the level of intra-abdominal fat and has a clear association with the risk of metabolic disease in adults [1]. Its meaning and use in children is less certain. However, recent studies have indicated that waist circumference correlates well with the level of truncal fat and that this is also associated with markers of cardiovascular risk [21]. Waist circumference also appears to track through childhood and adolescence into adulthood [22].

Waist circumference is cheap, easy to assess and has a relatively low intra- and inter-observer variability. However, at present the work linking waist circumference to ill health in children is still very limited and there have been no cut-off points defined. In addition, waist circumference is only a measure of abdominal rather than total adiposity and so is not useful on its own as an indicator of obesity.

Other Circumferences and Ratios

In adults, the most commonly used circumferences for assessing body fat distribution have been waist, hip and thigh. These sites have been measured also in children, but the significance of these measurements and the ratios derived from them in relation to adiposity is not clear in childhood. In addition, no growth charts are available.

In addition, mid-upper arm circumference has been used to monitor underweight in pre-school children. It might also be a useful measure for assessing fatness during later childhood [10].

Skinfold thickness and arm circumference served as a basis for equations, which were developed in France to assess body composition in children. In this development, triceps skinfold thickness together with upper arm circumference were used to calculate fat and muscle areas and to produce equations, which were validated against magnetic resonance imaging (MRI). The authors concluded that as a result, upper arm fat area estimates and upper arm muscle area are simple and accurate indexes to assess body composition. French reference values are available from 1 month to 17 years of age [23].

In a US study, the relationships of intra-abdominal adipose tissue (IAAT) and subcutaneous abdominal adipose tissue (SAAT) with body composition and anthropometry were examined by using dual energy X-ray absorptiometry (DEXA), skinfolds and circumferences in Caucasian and African-American pre-pubertal children. IAAT and SAAT were found to be predictable from a series of regression equations both with and without the availability of DEXA. For example, the optimal approach for estimating SAAT was from waist circumference, subscabular skinfold and height, which explained 92% of the variation. Abdominal skinfold, subscapular skinfold and ethnicity explained 80% of the variance in IAAT [22].

Measures of Body Composition

A number of techniques have been developed for estimating body composition, total body fat stores and fat distribution. Because of the need for expensive equipment or highly specialized staff, their use is usually restricted to research or tertiary care centers. Estimates of adiposity from these techniques has been used in the past for defining obesity in children but the absence of any standards, the cost and inconvenience of measures negates their value as a measure of obesity. However, because they produce more reliable estimates of body fat stores they may be used to help validate more practical anthropometric measures. Body composition measurements are described elsewhere in this publication.

Current Practices for Definitions

Body mass index (BMI) has now been accepted as the most appropriate and useful measure of relative adiposity in adults and the World Health Organization has set out a universal system of classification to identify those adults overweight or obese. However, a range of measurement and classification systems still persist in the assessment of children with relative weight for height and age remaining the most widely used measure of adiposity in children but BMI for age appears to be often applied in adolescents. There is a growing consensus that BMI for age should be applied to the assessment of weight status in children of all age but much confusion remains about how to choose an appropriate reference population and how to select appropriate cut-off points for defining a child as overweight or obese.

Current WHO Definitions

The current recommendations from the World Health Organization for defining overweight and obesity in children and adolescents highlights the complexity of the current situation. WHO recommends that weight-for-height Z-scores are used as definition for obesity in children aged 10 years or less. In adolescents (aged 10–19 years), WHO defines at risk of overweight as an age-sex-specific BMI greater than the 85th percentile of the reference population. Both these definitions require the use of growth standards or references and since the late 1970s, WHO has proposed the development of new international growth reference curves and BMI reference curves [24]. The WHO international reference curves for children and infants aged less than 5 years has been in development for a number of years, but as yet these have not been published.

At present, WHO recommends the use of height and weight reference data for populations produced by the National Center for Health Statistics (NCHS). The original NCHS/Centers for Disease Control (CDC) growth curves were formulated in 1975 by combining growth data from four sources in order to serve as a reference for the United States (US). WHO adopted this NCHS/CDC reference as the international reference in 1978. The original height and weight distributions were slightly modified in 1980 when a software version of the reference curves was developed by CDC. However, the WHO committee has drawn attention to several technical and biological problems with this reference particularly as there are currently large variations in the feeding patterns and rate of growth across different countries.

Part of the problem with definitions of childhood and adolescence based on existing reference charts is that these were developed to assess the growth of children and adolescents with a focus on identifying failure to thrive and inadequate nutrition. At the time of their development the problems of undernutrition were far more prevalent than those of overnutrition. With the major shift in the weight status of children and adolescents throughout the world towards overnutrition, extrapolating standard growth charts to define children and adolescents with excessive adiposity may not be appropriate.

A Strong Influence of the US Determination

The difficulty and expense of large longitudinal studies following the growth of children over time has meant that there are few countries that have their own standard growth curves and as a consequence many countries rely on data and definitions set by the US. The influence of the original NCHS definitions and reference cut-off points derived from NHANES data has been strong, since several studies also outside the US have applied this reference in their national dataset to assess the prevalence of obesity. Although other international approaches exist and the US has since developed newer methods for defining weight status in children, the NCHS reference is still in use throughout the world.

In the early 1990s, an expert committee recommended obesity to be classified in the US on the basis of the BMI distribution in the reference population, with the 85th percentile being the cut-off point for at risk of overweight and the 95th percentile for overweight [11]. In an attempt to avoid reference percentile being determined from a population which is already too heavy, a reference population was produced from children and adolescents studied by the US National Center for Health Statistics (NCHS) in early 1970s [25].

Recent Proposals for Definitions

National Approaches

United States

The Centers for Disease Control and Prevention (CDC) has recently developed new growth charts, which include an age- and sex-specific BMI reference for children and adolescents aged from 2 to 20 years of age (fig. 1, 2). These charts also include a sex-specific weight-for-height reference for children aged 2–6 years. Data from five national health surveys carried out between 1963 and 1993 together with five supplementary sources of data serve as the reference population for developing for these curves.

Each of the CDC BMI-for-age gender-specific charts contains a series of curved lines indicating specific percentiles. Healthcare professionals use the following established percentile cut-off points to identify underweight and overweight in children. Based on the specific percentiles, the definitions for children being underweight, at risk of overweight or overweight are as follows:

Underweight	BMI-for-age $<$5th percentile
At risk of overweight	BMI-for-age 85th to $<$95th percentile
Overweight	BMI-for-age $\geq$95th percentile

The terminology of at risk of overweight and overweight (which in adults equates to overweight and obesity) is in line with the terms used by WHO to the weight status of adolescents as defined by their BMI for age curves.

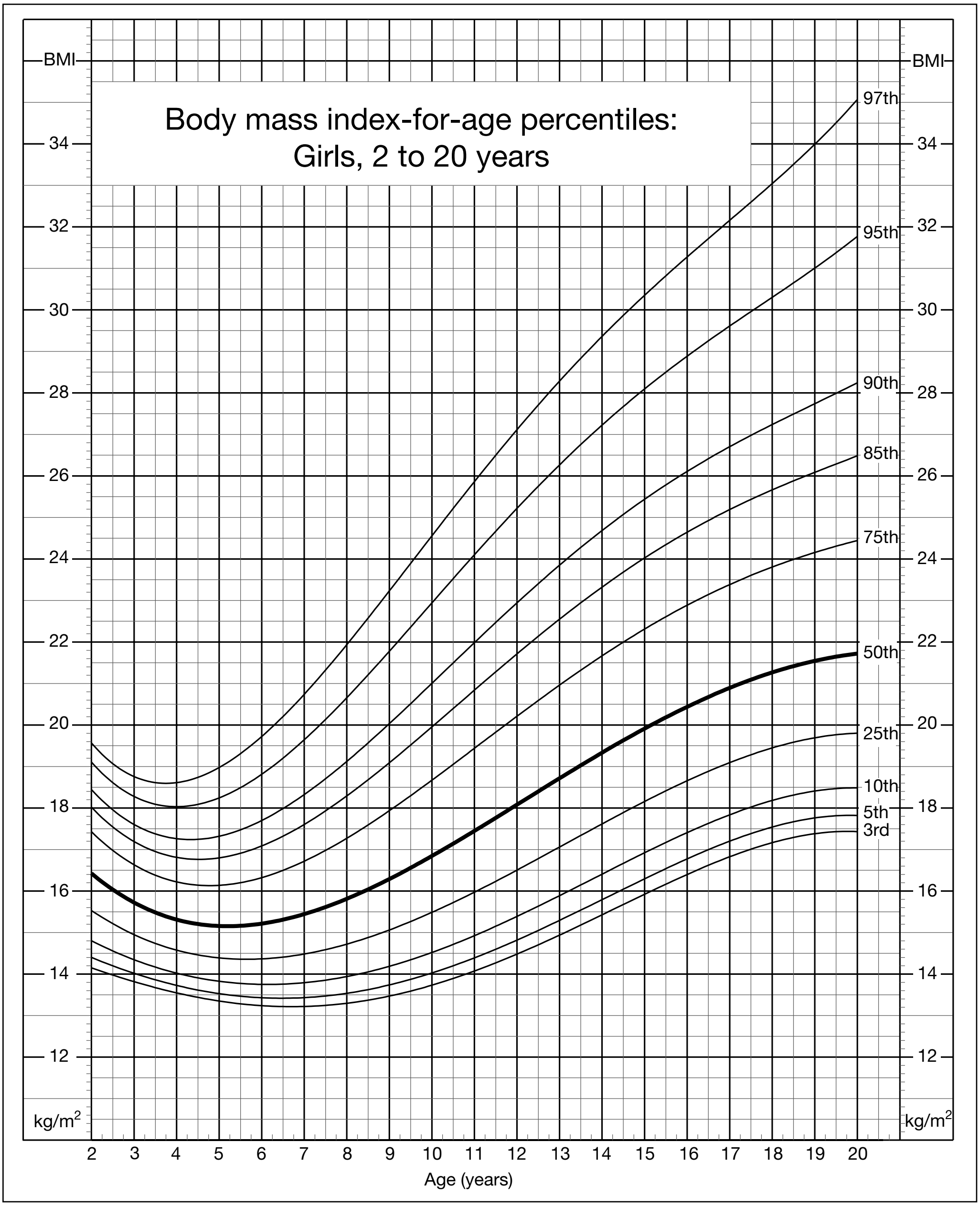

Fig. 1. CDC growth charts from the United States: BMI for age percentiles for girls aged 2–20 years. Source: The Centers for Disease Control and Prevention, 2000.

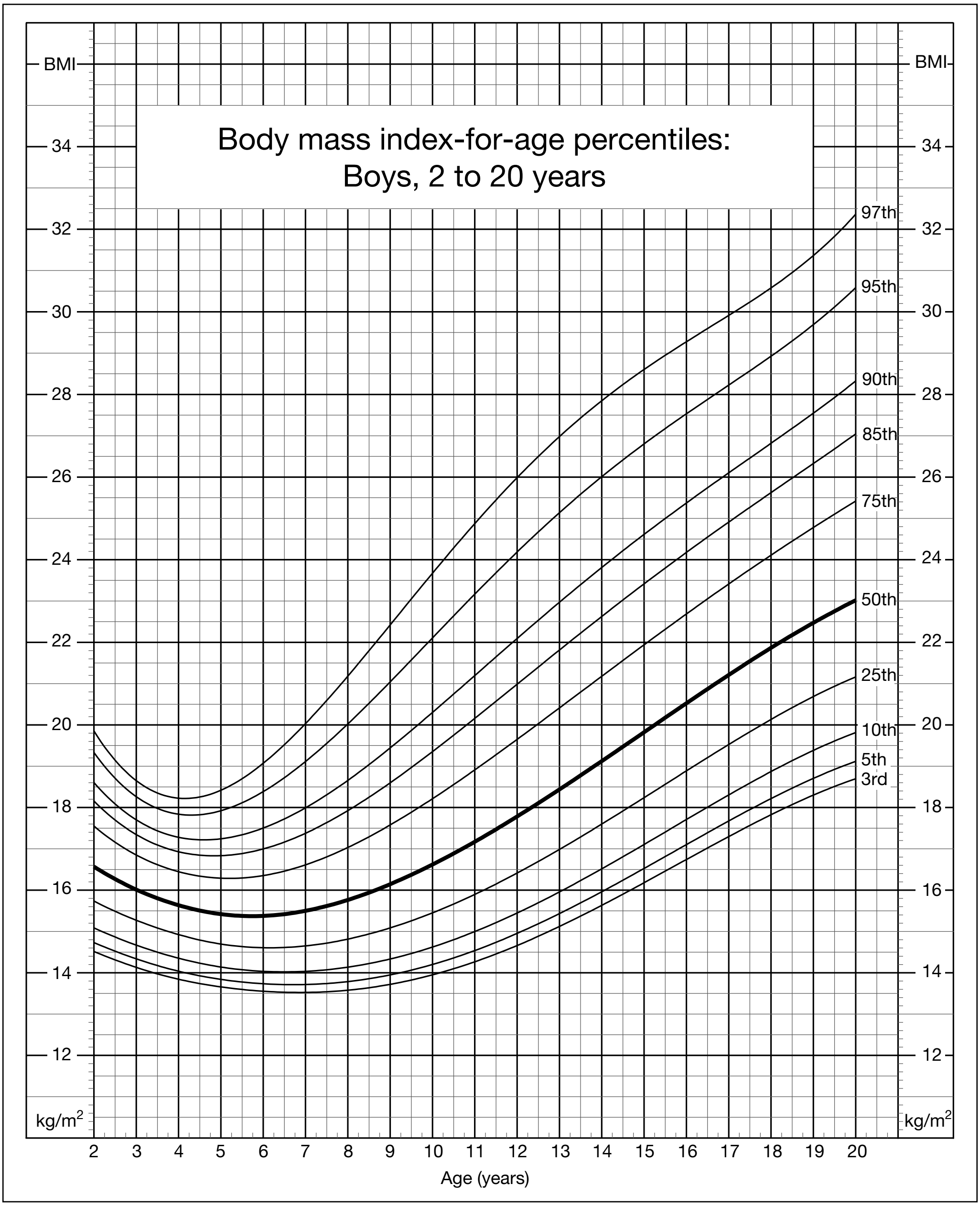

Fig. 2. CDC growth charts from the United States: BMI for age percentiles for boys aged 2–20 years. Source: The Centers for Disease Control and Prevention, 2000.

Other Countries

In addition to the US, some other countries have quite recently developed their own BMI-for-age reference charts. To date, such charts based on the local data have been produced for example in the United Kingdom [26], the Netherlands [27], Italy [28], France [29], Sweden [30] and Hong Kong, China [31]. Cut-off points for BMI used to define those children and adolescents with a weight problem have varied considerably in different countries [32], with the cut-off points of the 85th and 95th percentiles being the most commonly used [1].

Australia recently set a working definition of childhood obesity and has just released a set of National Clinical Guidelines for Weight Control and Obesity Management in Children and Adolescents [33]. The document proposes that BMI should be used as the standard measure of overweight and obesity from 2- to 18-year-olds in Australia. It suggests:

- The international reference developed by Cole et al. [16] should be used in population and clinical research.
- BMI for age percentile charts should be used in clinical and non-healthcare settings, with a BMI above the 85th percentile indicative of overweight and BMI above the 95th percentile indicative of obesity (it notes that these definitions are arbitrary and that amore appropriate definition is needed).
- That local standards for BMI and waist circumference should be developed but in the intervening period that the CDC BMI percentile charts are used.

International Approach for Definitions

IOTF Workshop

The purpose of the workshop on childhood obesity in 1997 was to establish a reasonable index with which adiposity or overweight in children and adolescents could be assessed worldwide. The participants concluded that, although BMI was not a perfect measure of obesity, it had been validated against more precise body fat assessments, and thus was the most appropriate basis for defining overweight and obesity in children and adolescents. In addition, they suggested that, as BMIs of 25 and 30 have internationally acceptance as appropriate cut-off points for adults, percentile values at different ages corresponding to those BMIs at age 20 years would serve as the absolute reference cut-off point throughout childhood and adolescence [15].

International Reference Population

Based on the proposal made by the workshop organized by IOTF, age and sex specific cut-off points for BMI for overweight and obesity in children were developed by using dataset specific centiles linked to adult cut-off points.

Data for this development were obtained from six large nationally presentative cross-sectional surveys on growth from Brazil, Great Britain, Hong Kong, the Netherlands, Singapore and the US. For each of the surveys, centile curves were drawn such that they passed through cut-off points of 25 for adult overweight and 30 for adult obesity at age of 18 years. Averaging the curves from different surveys provided the age- and sex-specific cut-off points for BMI for overweight and obesity from 2 to 18 years. These cut-off points were tabulated at exact half-year ages (table 1). The cut-off points are recommended for use in international comparisons of prevalence of overweight and obesity among children and adolescents but were not deemed appropriate for clinical assessment [16].

The publication of Cole et al. [16] has raised much discussion in the literature concerning the evidence base, rationale, and practical issues in relation to an international approach to defining childhood obesity [34–37]. In recent publications, the international cut-off points have been compared with national definitions and have produced mixed results. A study of children aged 7 years in the United Kingdom tested the sensitivity of the IOTF international BMI cut-off points and the current UK BMI curves at classifying children identified as having excessive adiposity by bioelectrical impedance analysis (BIA). The authors concluded that the existing UK definition produced a much higher sensitivity and specificity than the IOTF approach to defining childhood obesity, especially for boys [38]. Another UK study also compared these two definitions in children aged 4–11 years. Compared to the UK reference, the international cut-off points exaggerated the gender difference in the prevalence of overweight and obesity and resulted in lower estimates for the prevalence of obesity [39]. The prevalence of overweight was also lower using the IOTF definition in children aged 2–14 years in a US study, where this definition was compared with the revised CDC growth charts. However, the opposite was true in adolescents aged 15–19 years [40].

A recent French study used four different definitions based on body mass index to assess the nutritional status (obesity, overweight and thinness) of French children aged 7–9 years. The references used to define grades of nutritional status were: (1) the French BMI reference standard to define thinness and overweight (3rd and 97th percentiles, respectively); (2) the Must et al. [25] standard to define thinness, overweight and obesity (5th, 85th and 95th percentiles, respectively); (3) the IOTF cut-off points to define overweight and obesity, and (4) the revised CDC standards to define thinness, overweight and obesity (5th, 85th and 95th percentiles, respectively). According to these definitions, overweight affected 16, 24, 18 and 21% of children, respectively, whereas the prevalence of obesity was 9, 4 or 6% based on the three latter definitions. Although each definition produced wide variation in estimates of total overweight and obesity, little difference was observed between sexes [41].

Table 1. International cut-off points for body mass index for overweight and obesity by sex in children and adolescents aged between 2 and 18 years defined to pass through body mass index of 25 and 30 kg/m^2 at age 18

Age	Body mass index 25 kg/m^2		Body mass index 30 kg/m^2	
years	males	females	males	females
2	18.41	18.02	20.09	19.81
2.5	18.13	17.76	19.80	19.55
3	17.89	17.56	19.57	19.36
3.5	17.69	17.40	19.39	19.23
4	17.55	17.28	19.29	19.15
4.5	17.47	17.19	19.26	19.12
5	17.42	17.15	19.30	19.17
5.5	17.45	17.20	19.47	19.34
6	17.55	17.34	19.78	19.65
6.5	17.71	17.53	20.23	20.08
7	17.92	17.75	20.63	20.51
7.5	18.16	18.03	21.09	21.01
8	18.44	18.35	21.60	21.57
8.5	18.76	18.69	22.17	22.18
9	19.10	19.07	22.77	22.81
9.5	19.46	19.45	23.39	23.46
10	19.84	19.86	24.00	24.11
10.5	20.20	20.29	24.57	24.77
11	20.55	20.74	25.10	25.42
11.5	20.89	21.20	25.58	26.05
12	21.22	21.68	26.02	26.67
12.5	21.56	22.14	26.43	27.24
13	21.91	22.58	26.84	27.76
13.5	22.27	22.98	27.25	28.20
14	22.62	23.34	27.63	28.57
14.5	22.96	23.66	27.98	28.87
15	23.29	23.94	28.30	29.11
15.5	23.60	24.17	28.60	29.29
16	23.90	24.37	28.88	29.43
16.5	24.19	24.54	29.14	29.56
17	24.46	24.70	29.41	29.69
17.5	24.73	24.85	29.70	29.84
18	25.00	25.00	30.00	30.00

From Cole et al. [16].

Furthermore, Wang and Wang [42] compared different references (IOTF, WHO and CDC) for assessing child and adolescent overweight and obesity in different populations by using data from cross-sectional studies carried out in children aged 6–18 years from the US, Russia and China. In assessing overweight, there was good agreement between the reference standards in general, although they varied by sex-age groupings and countries. Overweight prevalence was twice as high in children (6–9 years) than in adolescents (10–18 years) in China and Russia, but was similar in the US. On the contrary, estimates of obesity prevalence using these three references varied substantially.

Definitions Not Dependent Upon a Reference Population

Currently used definitions of childhood overweight and obesity are all dependent upon generating some form of cut-off points from a reference growth curve. Even if a truly international reference growth curve could be developed the process still relies on identifying norms of body weight or circumference. However some recent studies have suggested that defining obesity in terms of biological endpoints rather than population distribution will overcome this limitation. In an Australian study, the percent body fat was calculated from the sum of four skinfolds, and was compared against levels of cholesterol and triglycerides [43]. Based on associations found, the authors concluded that a cut-off point of 30% body mass as fat for girls and 20% of boys aged 9 or 15 years appeared to be an appropriate standard for defining obesity. These results were in agreement with the findings from Bogalusa study in the US [44], which resulted in the cut-off points of 30% for girls and 25% for boys.

Another study from Taiwan utilized performance in a range of physical fitness tests as an outcome for determining BMI cut-off points appropriate for children aged 7–18 years. The relationship between BMI and performance of fitness tests was examined in 878,207 students participating in a nationwide fitness survey in Taiwan. They found a strong relationship between BMI and fitness level based on a composite score from four separate tests. When they excluded the unfit students (poorest quartile), the 85th and 95th BMI percentile values of the fitter students were in line with the adult cut-off points of 23 and 25 kg/m^2, which, according to the authors, have been recommended as the Asian criteria for overweight and obesity in adults [45].

Special Issues Concerning Universal Definitions

Ethnicity: Body Stature and Fat Content at Given BMI

Although BMI is generally accepted as a reasonable measure of body fatness, there is some, but not consistent evidence that the relationship between

BMI and adiposity is not constant throughout a population and may vary greatly between different ethnic groups both in adults [46, 47] and children [25, 48]. The reason for the different relationships between BMI and body fatness in different ethnic populations is not known. However, variation in relative subcutaneous fat distribution and in the relative proportions of the trunk and lower extremities to the height have been suggested to be potential causes of these differences and confounding factors in the use of the BMI as an index of adiposity [49]. For example, Asian adults have been shown to have relative shorter legs and slender body built (i.e. likely to have less muscle mass) than Caucasians [50]. As a result, for a given BMI Asians may have more fat [47, 50] and a higher risk for obesity-related diseases [51] than Caucasians. The resulting underestimation of obesity by applying international BMI standards has been reported, for example, among Chinese, Malays and Indians living in Singapore [52] as well as other Asian nationalities living in the US [53, 54]. Whether higher body fat at a lower BMI corresponds also with an increased risk of morbidity and mortality remains to be determined [50]. Furthermore, the implications in children and adolescents of these possible racial/ethnic differences in the relationship between the true proportion of body fat and BMI are even less clear than in adults. Two studies have reported that Caucasian children had higher body fatness for a given BMI than African American children [55, 56], whereas no differences in relation between BMI and body composition were found in European, Maori and Pacific Island children [57].

Ethnicity: Timing of a Growth Spurt and Sexual Maturation

Individuals and populations differ in the timing and tempo of the adolescent growth spurt (and sexual maturation), which may have an effect on the interpretation of BMI in childhood and adolescence. On average, the lower extremities experience maximum growth before maximum growth in the trunk, but the major increase in body mass is more coincident with growth of the trunk [7]. Individuals and populations vary not only in the timing of peak height velocity during the adolescent spurt but also in sexual maturation [58–60]. These events appear earlier in countries where individuals experience the longest life expectancies. For example, the age at menarche is among the lowest in many southern European countries as well as in Japan and China, whereas in Malaysia and South Korea sexual maturation seems to occur later [60].

Failure to account for population and individual differences in maturation status may lead to misclassification of adolescents who differ in rates of growth and maturation from the reference population, since fatness and BMI has been shown to be more closely associated with maturation stage than chronological age [61]. In a recent paper, the effect of adjusting for difference in timing of maturation when assessing the prevalence of adolescent overweight in different populations was investigated. As a result of the maturity adjustment, the estimated prevalence of overweight increased in China and Russia, where girls mature later than the reference population (US NHANES I). The overall effects of adjustment, however, were quite small [62].

A combined effect of pubertal status and ethnicity on skeletal muscle mass and bone mass was examined in white, black and Asian children aged 6–18 years living in New York. The correlations between lean mass indicated by total body potassium (TBK) and bone size indicated by total body calcium (TBCa) were studied and TBK/TBCa was compared between sexes, pubertal stage groups and ethnic groups. TBK/TBCa decreased as body weight increased in prepuberal girls, and decreased as body weight and age increased in pubertal girls, but did not change with body weight or age in boys of any subgroup. No significant differences were found between whites and Asians [63].

Underweight and Stunting

The majority of studies examining whether BMI is a good indicator of fatness in children and adolescents have been carried out in populations living in developed countries. The value of BMI cut-off points for overweight has received less attention in malnourished populations in developing countries, where stunting and wasting are common. Some concerns have been raised about the ability of reference standards to detect both overweight and underweight with the same high level of sensitivity and specificity. The IOTF international definitions for childhood overweight and obesity [16] do not have equivalent cut-off points to define underweight, which limits their use in assessing weight status throughout the Asian region. However, the new CDC BMI-for-age charts do attempt to define underweight from the same reference curves using the 5th percentile as the cut-off point for underweight (see above).

Stunting and its effect on definitions of obesity is another key issue to consider. It is known that BMI is not a perfect measure in children, partly because it covaries with height [64]. In a recent study, the correlation between BMI and other indicators of fatness (skinfold thicknesses) were examined in rural Guatemalans. In this study, BMI was found to be a good indicator for overall fatness, but poor as an indicator for central fat. However, in stunted children BMIs were high despite small extremity skinfold thicknesses. The authors concluded that BMI alone should be interpreted with caution, since it may overestimate the prevalence of fatness in stunted children [65].

A paper by Popkin et al. [66] examined the relationship between stunting and overweight status for children aged 3–6 and 7–9 years in Russia, Brazil, and the Republic of South Africa and China. Using identical cut-off points for BMI, the prevalence of overweight in these countries ranged from 10.5 to 25.6% (based on the 85th percentile). Stunting was also common affecting 9.2–30.6%

of children in surveyed countries. These results showed a significant association of stunting with overweight status as well as with high weight-for-height in a variety of ethnic environmental and social backgrounds.

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