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From body mass index to body composition analysis in diagnostic of childhood obesity

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Abstract

Background: The prevalence of obesity increased worldwide in children and adolescents from 1975 to 2016. The recent increase in childhood obesity has led to an interest in the question of which definitions should be used to distinguish the obese child. Body mass index (BMI) was recommended for use in children to assess body weight status. There are several international (World Health Organization, International Obesity Task Force, Center for Disease Control) and national BMI cut-offs references, and it is a major obstacle in studying global secular trends for younger age groups. Moreover, BMI does not distinguish between increased mass in the form of fat, lean tissue or bone, and hence can lead to significant misclassification. The ideal monitoring tool should directly assess adiposity. All available body composition methods in children are indirect. The gold standard for body composition is the four compartment (4-C) model. Although bioelectrical impedance analysis is most susceptible to imprecision when compared with the 4-C model it is the most logical bedside method to apply in children owing to its low cost, noninvasiveness, lack of radiation exposure and ease of use.

Conclusions: BMI may produce a significant level of misclassification. Population-based cut-off values for body fat determined by body composition reference methods are the best criterion. Bioelectrical impedance is inexpensive, portable, simple and rapid to use. Further studies to elucidate the relationship among BMI, body fatness, fat distribution, and health risks in children should be followed.

Key words: body mass index, children, obesity, body composition, bioelectrical impedance analysis.

Introduction

Obesity is the most important nutritional-health problem of children and teenagers in developed countries [1]. Because of urbanization, life style change, and modernization, mean body mass index (BMI) and prevalence of obesity increased worldwide in children and adolescents from 1975 to 2016 [2]. According to the World Health Organization (WHO) report, more than 1.9 billion of adults (39%), 41 million children under 5, and 340 million children aged 5-19 have already been overweight in 2016 [1]. However, if post-2000 trends continue, child and adolescent obesity is expected to surpass moderate and severe underweight by 2022 [1].

The WHO defines obesity as an excess in fat mass great enough to increase the risk of morbidity, altered physical, psychological, or social well-being and/or mortality [2]. Obese children are more likely to become obese adults, and the biological changes that lead to obesity-related cardio-metabolic disease start to develop in childhood. In addition, hypertension, left ventricle hypertrophy, and high serum lipids have already been described in children with obesity. Other obesity related disorders such as T2DM, depression, sleep disorders, and asthma have been observed in children as well [27]. Obesity early in life is considered to be a risk factor for death from cardiovascular disease and from all causes in adulthood; such obesity may limit the increase in life expectancy that otherwise would be achieved. Despite progress in prevention and treatment of cardiovascular disease, cardiovascular mortality among young adults either has not declined or the decline has slowed over recent decades in several developed countries coincident with the obesity epidemic [9,10 29].

BMI for definition of obesity in children. There is now considerable concern over the trend towards increasing fatness in children, and in the recent marked increase in childhood obesity. These trends have led to an interest in the question of which definitions should be used to distinguish the obese child, and whether the same definitions are appropriate for clinical practice and epidemiology [3].

An ideal measure of body fatness should meet several requirements: it should be accurate in assessing the amount of body fat; it needs to be precise with small measurement error; the measure can predict risks of health consequences; it should be possible to develop cut-offs to separate individuals according to their adiposity-related health risks and it needs to be feasible in terms of simplicity, cost and ease of use, and acceptability to the subjects [4]. Although none of the existing measures satisfies all these criteria, the current consensus is that BMI is probably the best choice among available measures [3]. BMI calculated as weight in kilograms divided by the square of height in meters (kg/m2), is a measure of weight adjusted for height, as the scaling of body weight to height across adults provides powers rounded to 2 [5]. It was first described in the 19th century by a Belgian mathematician who noticed that in people he considered to be 'normal frame', the weight was proportional to the height squared [6]. Actual BMI has been recommended for use in children, adolescents, and adults to assess body weight status [3, 4], but whereas in adults the BMI cut points that define obesity and overweight are not linked to age and do not differ for males and females, in growing children BMI varies with age and sex [5,7].

Growth curves giving BMI distribution as a function of age and sex have then been elaborated so as to ensure more adapted application of this tool in the pediatric population [2]. The curves currently available were developed in response to the need for appropriate evaluation of body weight status and obesity in children on a national level (e.g. France, Germany, Great Britain, India, China) and/or internationally (e.g. WHO International Obesity Task Force, IOTF) [2, 7]. There are widely used three classification systems for ages 5 to 18 years which were developed with different objectives [8].

In the early 1980s the first BMI charts were published [11]. Following publication of French BMI references, Must's references generated from data gathered in the National Health and Nutrition Examination Survey I (NHANES I) in the USA were published in 1991, and their use was recommended by the WHO in 1995 [12]. Subsequently, other references from various countries were published. In 2000 in the USA, the Centers for Disease Control (CDC) and Prevention published sex-specific BMI-for-age growth charts [13]. Generally, references were based on nationally representative data, without selection criteria for feeding practices. The new WHO standards, released in 2006 for assessing the growth of children from birth to five years of age, were constructed differently [14]. They were created from samples made up of healthy breast-fed children from various countries around the world, and were intended to present a 'standard 'of physiological growth rather than a descriptive "reference" [8]. In order to extend these growth curves to school age children and adolescence, in 2007 the WHO developed references for 5- to 19-year-olds based on data from US surveys [15, 11]. In 2000, the International Obesity Task Force (IOTF) developed BMI centiles constructed on the basis of 6 nationally representative data sets to define childhood overweight and obesity [16]. As for the CDC [13] and WHO references [14], the same data from US surveys were incorporated in the IOTF references, leading to some similarities between reference curves (tab.1) [11, 21].

The US BMI-for-age reference is based on nationally representative data from boys and girls ages 2–20 years collected between 1963 and 1980 [2]. National reference standards are also in use in the UK, and are under development elsewhere [7]. Controversy exists about whether and under what circumstances a national or international reference standard is best [7]. The IOTF references have several advantages: they are internationally based and, because they are built to pass through adult cut-offs which are linked with mortality rates, they are less arbitrary than other cut-offs; they are also less geographically and temporally dependent than some other references [11]. WHO standards and references also have several advantages: they display data from birth and references for various anthropometric measurements. In addition, the WHO software converts anthropometric measurements into SDS allowing to express measurements as continuous variables and to define high levels of excess weight [11].

Moreover, the fact that the comparison with the IOTF and the CDC and the WHO reference give different prevalence estimates proves that these references represent populations between them. Perhaps in this case, it will be more appropriate to develop and use a local reference, in particular for BMI for age, where body distribution of fat might be more genetically determined [8]. Thus, the plethora of references that can be used makes it difficult to choose between them and to have a clear idea of childhood obesity prevalence worldwide [11]. The methodological problem of inconsistency between criteria of childhood obesity classification is a major obstacle in studying global secular trends for younger age groups [17].

Table 1

Common classifications of Body Weight (adults and children)

Classifications of BW (adults and children)	Age	Indicator	Normal Weight	Overweight	Obese
Adults	≥20 years	BMI (kg/m2)	18.50 to 24.99	≥25.00 Preobesec: 25.00 to 29.99	≥30.00 Class 1: 30.00 to 34.99 Class 2: 35.00 to 39.99 Class 3: ≥40.00
Children					
WHO 2006	0-60 months	BMI Z or WH Z	>−2 to ≤2 SD risk of overweight:>1 to ≤2 SD	>2 to ≤3 SD	>3 SD
WHO 2007	5-19 years	BMI Z	>−2 to ≤1 SD	>1 to ≤2 SD	>2 SD
IOTF	2-18 years	Growth curve for BMI at age 18		BMI = 25	BMI = 30
USA	2-19 years	BMI percentile	≥5th to <85th	≥85th to <95th	

Abbreviations used: BMI, body mass index; IOTF, International Obesity Task Force; SD, standard deviation; WHO, World Health Organization; WH weight-for-height; Z, z score.

Limitations of BMI. Although it is common to use BMI for determining obesity, where only height and weight are needed to be measured, it is not an accurate criterion for obesity evaluation [3,16,18,22,27]. Weight can be divided into two components: FM (fat mass) + FFM (fat free mass). FFM is a complex tissue compartment composed of skeletal muscle, organs, bone, and supporting tissue [30]. The FFM and FM indices are equivalent concepts to the BMI (as the denominator is the same), and result from the partitioning of BMI into two subcomponents using body composition, namely, BMI kg/m2= FFMI kg/m2 + FMI kg/m2; hence FFMI = (BMI - FMI) and FMI = (BMI- FFM) [28,35].

Thus, FFMI and FMI use similar ratios for their calculation as does BMI, the only difference being that the numerator is composed of FFM or FM rather than body weight also in kg. Considering the equation above, an increase (or a decrease) in BMI could be accounted for by an increase (or a decrease) in either subcomponents (FFMI or FMI) or in both components [28]. BMI does not distinguish between increased mass in the form of fat (FM), lean tissue or bone (FFM), and hence can lead to significant misclassification [3,6,18,27,28]. For example, body builders and competition athletes in other power and strength sports (boxing, shot put, wrestling and culturism) have a low proportion of fat in the body, but their BMI is often in the overweight/obese range because of their large lean (muscle) mass [28]. On the basis of their BMI, normal individuals may carry a high percentage of body fat [19], almost during puberty. Although weight gain is also a result of increased muscle mass and adipose tissue in both sexes during puberty [9], the gain in muscle mass is higher in boys and that for adipose tissue is higher in girls and normal children by BMI/age, may carry excess body fat and are metabolically similar to those carrying excess weight [18,19]. Thus, unlike in adults where BMI is generally uncorrelated with stature, some studies show that BMI and stature are related in children, particularly during early adolescence in boys, so, children and younger adolescents, particularly boys, who are tall for their ages may have large BMI values as a consequence of stature rather than excess adiposity [20,31,32]. The BMI alone cannot determine the nutritional status of overweight or obese adolescents, limiting its exclusive use [19,27]. Sidhu *et al.* analyzed sensitivity, specificity, and accuracy of BMI in determining high body fat mass by conducting a study on 500 girls within the age range of 6- to 11-year old. In this study, the BMI of equal to and more than the 95^{th} percentile of CDC standards was regarded as obesity and the fat mass (measured by caliper) of equal to or more than the 90^{th} percentile was regarded as having high fat mass. This study reported sensitivity, specificity, and accuracy as 42%, 85%, and 87%, respectively. Also, it concluded that using BMI by itself was not appropriate for determining high fat mass and suggested using another indicator along with BMI for determining obesity and high body fat mass [22].

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. Another study was focused on the ability of BMI with 85th to 94th percentiles to identify children with high body fat correctly. Among children who had a BMI for age between the 85th and 94th percentiles, about one-half of these children had a moderate level of fatness, but 30% had a normal fatness and 20% had an elevated fatness [5]. A study comparing Asian prepubertal children from New York City (NYC) and Jinan, Shandong, mainland China stated that although no differences were found in mean BMI, Jinan Asians had significantly higher percent body fat (%BF) compared with the NYC Asians ($P<0.001$), being both samples collected from urban settings on two separate continents [17]. Low-moderate sensitivity as a marker of adiposity is a problem for public health applications such as surveillance of obesity, because large numbers of children with excess body fat will not be identified [7].

Body composition reference methods. Since the pathology associated with obesity is driven by the excess fat mass, the ideal monitoring tool should directly assess adiposity [18]. Population-based cut-off values for body fat determined by body composition reference methods are theoretically the best criterion for the definition of overweight and obesity [2]. It should be emphasized, however, that body fat is measured with a much greater error than body weight and height. Consequently, this would explain why any potential superiority of body composition measurements over BMI in predicting health risks is difficult to demonstrate [28]. Still, over the past several decades body composition methods have been gaining acceptance in both research and clinical medicine [4,39]. Many studies have demonstrated that adult body composition measurement methods and data may not be directly applicable to pediatric populations [5,6,9].

Despite the fact that numerous techniques are now available for estimating body composition, there is no single method for measurements in vivo [30]. All methods incorporate assumptions that do not apply in all individuals, and the more accurate models are derived by a combination of measurements, thereby reducing the importance of each assumption [28].

All approaches to body composition analysis can be organized according to the number of compartments described. *Two-compartment models* (2-C) divide the body into fat mass (FM) and fat free mass (FFM) such that total body mass = FM + FFM [30]. The direct measurement of body fat mass has never been easy and remains a significant challenge for most body composition techniques. However, if one can determine the total FFM, then body fat can be defined indirectly as the difference between body weight and FFM. The 2-C model, which has been used in body composition research for more than 50 years, continues to serve a vital role, especially in the evaluation of newer technologies focusing on body fat assessment [35]. Two compartment methods include anthropometry, densitometry, bioelectric impedance, or isotope dilution for total body water. *Three-compartment (3-C) models* divide body mass further into FM, non-osseous lean body mass (LBM) and bone mass such that total body mass = FM + LBM + bone mass. In this 3-C model, the FFM is divided into two parts: its water content and the remaining solids (predominately protein and minerals) [35]. For this 3-C model, the density of water, fat, and body solids are used. The results obtained using this model provided some improvement over the basic 2-C model for healthy adults and older children. However, for patients with significantly depleted body protein mass and/or bone mineral mass, the estimated values for the density for the solids compartment would be incorrect; thus the final estimate of body fat mass was also inaccurate [35]. DXA offers a quick, convenient means of three compartment analysis. Because DXA measures bone mineral content directly, this method eliminates one of the major sources of variability inherent in the estimation of the FFM in the two-compartment model [30, 37]. To extend the basic 2-C model to *four compartments (4-C)*, one would need an accurate measure of the protein and mineral compartments, in addition to that of total body water. For this four-component model, the densities for body protein and bone mineral can be assumed as 1.34 and 3.075 kg/l, respectively. Multicomponent models using methods or combinations of methods to measure FM + three or more components of FFM have also been developed. The accuracy of body composition assessment improves with the number of components measured as there is less dependency on the assumption that FFM density is constant [30]. For example, the formula for a 4-C model might include density values for fat, water, mineral and protein [36]. However, the 4-C model is generally not available to clinicians, because of the need for specialized equipment. Although other methods, such as quantitative computed tomography, magnetic resonance imaging and magnetic resonance spectroscopy, are used to determine the quantity and quality of adipose tissue, skeletal muscle and other internal tissues and organs, they have limited usefulness for the clinician, because they are not necessarily available for nondiagnostic use, are expensive and require highly specialized equipment and technicians and may expose children to radiation (for example, neutron activation, computerized tomography scan) [4,36]. Thus, the clinician must primarily rely on techniques that are based on the two-compartment model for routine determination of body composition in children, including dual-energy X-ray absorptiometry (DXA), dilution techniques, hydrodensitometry (also known as underwater weighing) and air displacement plethysmography, single- and multi-frequency bioelectrical impedance analyses (BIA).

Dual-energy X-ray absorptiometry (DXA) devices estimate FM% with acceptable accuracy and have become the reference method for estimating body composition [2]. DXA is a widely recognized method of body composition analysis that beyond BMD provides information of the nutritional status of the patients, including fat reserve and lean soft tissue [26]. However, their drawbacks are radiation exposure, relatively high cost, and limited accessibility. Bioelectrical impedance techniques are typically developed and validated against DXA, dilution and/or hydrodensitometry techniques, which serve as reference methods for that purpose [6,10].Compared to DXA, bio impedance analysis (BIA) has been shown to provide a good degree of accuracy in various populations [21].

Although BIA was the technique most susceptible to imprecision when compared with the 4-C model [12], it is the most logical bedside method to apply in children owing to its low cost, noninvasiveness, lack of radiation exposure and ease of use and better reproducibility compared with other bedside techniques, such as skinfold measurements [4,18].

The bioimpedance (BIA) method is based on the concept that tissues rich in water and electrolytes conduct better the flow of an electrical current than adipose tissue. Bioimpedance systems measure the impedance of a low energy electrical signal as it flows through body tissues; impedance is proportional to the conductor length (i.e., height) and inversely proportional to the conductor crossectional area. Four electrodes are usually attached to the individual during measurement: from hand to hand and from foot to foot with the subject standing. Conduction of the electrical current through body tissues is related to the water and electrolyte content of the tissue [4,6]. It is important to note that measurement conditions are fundamental for obtaining accurate BIA body composition estimates. The BIA model, the equation used for body composition estimation, room and subject temperature, body position, electrode placement and several other factors (e.g., eating or drinking, dehydration, exercise) can all influence measurements and should be standardized during measurement. The subject must be lying horizontal at least 5 min or more before measurement, to allow an even distribution of all the body fluids. In presence of fever BIA data are not valid. Since the volume to be assessed is the entire length between the foot and the arm it is important to avoid any contact that short circuits such pathway. If the subject is not dressed, arms and legs must be separated from each other, or insulated. To avoid acute fluid shifts, subjects will be instructed to refrain from strenuous exercise for 12 h before the measurement. The examination must be done after an overnight fasting. Room temperature must be kept between 20 and 24°C to prevent undesired effects on cutaneous blood flow or compartmental changes in water. Subjects will be measured while lying supine on a non-conductive surface [4].

Percent body fat (fat mass(kg)/body mass(kg)* 100) is obtained from body composition methods that estimates fat mass and provides more valuable information than BMI by differentiating between fat and fat free mass. A study comparing BMI to percent body fat (% FM) found that less than half of children and adolescents defined as overweight by BMI (BMI ≥ 85th percentile) had high adiposity defined by percent body fat [30]. Flegal M et al. showed that current BMI cut-offs can identify a high prevalence of high adiposity in children with high BMI-for-age and a low prevalence of high adiposity in children with normal BMI-for-age [33].

Nowadays, there is no consensus about %FM cut-offs for obesity in children and adolescents. Especially during adolescence, the level of adiposity may vary widely by age, sex and pubertal development [4]. Normal patterns of body fat include a decrease in body fat percentage after infancy and subsequent increase in body fat percentage until puberty. In normal growth and development in children, males gain more muscle and lean tissue than fat at puberty while girls gain more fat [6]. The reference values and chart created with selected percentiles of the normal adolescents might be helpful in growth assessment and obesity related risk evaluation [5]. The national percentile values of %FM, according to age and gender, were identified in many countries for evaluating distribution of body composition in adolescents [5,34]. In the absence of clear cut-off points, usually accepted %FM values for the definition of excess body fat range between 30–35% in female adolescents and 20–25% in males aged 4–6 years and 15–18 years [4].

The use of percent body fat (%FM) is limited by the fact that it does not take into account the effects of height, body proportion, and the independent contributions of absolute amounts of fat and fat free mass to health and disease [30]. Fat mass index (FMI) is obtained from dividing body fat mass (kg) by squared height (m^2) can be a proper criterion for predicting body fat mass and obesity. It provides the possibility for considering body fat mass separately and stating it relative to height [23]; it is used in some studies for determining obesity as a better criterion than body fat percent_[22]. FMI was found to be more sensitive indicators of nutrition status compared to BMI or percent body fat when applied to data from the Minnesota Semi-Starvation Study. Analyses of FMI and FFMI (fat free mass index) in children have revealed that increases in BMI during childhood are largely driven by increases in FFMI and not FMI, suggesting that BMI may not accurately represent adiposity in all situations [32].

By determining these indices, quantification of the amount of excess (or deficit) FFM and FM can be calculated for each individual. Thus, the calculation of FFMI will allow a clinician to identify a malnourished individual, whereas interpretation of BMI and FM% may fail to detect the presence of protein–energy malnutrition [38]. Although BMI is a useful tool to compare body weights in individuals who differ in height, FFMI and FMI are useful for the comparison of body composition in individuals who differ in height. The advantage of the combined use of these indexes is that one can judge whether the deficit or excess of body weight is selectively due to a change in FFM, FM or both combined. For example, an individual of 1.85 m and 100 kg, and hence having a BMI of 29.2 kg m2, would be judged as largely overweight and even borderline obese. This would be true if his FMI is higher than the reference values and conversely if his FFMI is not simultaneously elevated. Another advantage of FMI, as compared with the BMI concept, is that it amplifies the relative effect of aging on body fat. Expression of a change in relative body FM (%) alone fails to allow an appropriate comparison among subjects of different sizes. The high sensitivity of FMI (or conversely of FFMI) to a slight change in body fat stores (or conversely lean tissue mass), compared with the use of BMI or FM% as factors, makes it an index of potential interest for assessing static and dynamic nutritional status and energy reserve end points. The concept of FFMI could also be useful for calculating the relative muscle hypertrophy in bodybuilding and other sports, in which heavy muscular body build needs to be measured quantitatively to exclude false diagnosis of excess body fat based on single BMI measurements [28].

No reference values have been specified for FMI yet. The use of this index, which is promising but requires a valid assessment of body composition by the pediatrician, is increasingly under evaluation [28]. Reference intervals of FMI versus FFMI, for adults, children and teenagers, can be used as indicative values for the evaluation of nutritional status (degree of overnutrition or undernutrition) of apparently healthy subjects. It can also provide complementary information to the classical expression of body composition reference values. FMI is able to identify individuals with elevated BMI but without excess FM. Conversely, FMI can identify subjects with 'normal' BMI but who are at potential risk because of elevated FM [28]. It was observed that 79% of the obese children based on FMI were recognized to be obese based on BMI as well and 73% of the children with normal adiposity based on FMI showed the same status with BMI; in other words, sensitivity and specificity of BMI in comparison with those of FMI as the real criterion of obesity were 79% and 73%, respectively [22]. Based on these results, BMI compared with FMI as the real criterion of obesity had relatively lower sensitivity and higher specificity, i.e., BMI had less capability in recognition of obese individuals correctly and higher capability in recognition of individuals with normal weight as compared with FMI [22].

In the study by Haeri-Behbahani, the 90th percentile values of FMI for 6-11 years children were reported as 5,2, 5,9, and 5,6 (kg/m^2) for boys, girls, and total children, respectively. When FMI as the real criterion of obesity was applied, BMI sensitivity and specificity at equal to or more than the 95th percentile of the CDC 2000 standard for determining obesity were reported to be 43.3% and 99.4%, respectively, and the difference observed at the obesity level based on these two criteria was significant. Based on the results of that study, BMI had lower performance in obesity diagnosis in children and FMI was a better criterion than BMI for obesity evaluation in children [22]. In the study of Eto *et al.*, the validity of BMI and FMI was evaluated by considering body fat mass of more than 20% and 25% in boys and girls, respectively, as the real criterion of obesity in children and also determining the 90th percentile of the data obtained from calculating BMI and FMI for defining obesity. Thus, sensitivities of BMI and FMI were calculated as 37,5% and 68,8% in boys and 30,4% and 42,9% in girls, respectively. In their research, FMI showed higher sensitivity than BMI but both indicators demonstrated lower capability than body fat percent for diagnosing obese children. In addition, specificities of BMI and FMI were calculated as 95,5% and 99,5% in girls and 96,4% and 100% in boys, respectively, both of which showed high specificity [22, 28]. Due to observing a correlation between BMI and FMI on the one hand and body fat percent on the other, this study suggested both BMI and FMI as indicators of fat mass.

The study by Demarath et al. which was conducted on 494 girls and boys within the age range of 8-to18-year-old showed that FMI significantly increased only at high percentiles of BMI. Although means for BMI were similar in girls and boys, FMI was significantly different in the two genders. In this study, with the equal increase in BMI percentile, body fat increase with age in heavier girls was higher than lighter ones. This research concluded that changes in BMI percentiles in children might not properly show changes in body fat mass in the course of time, especially in boys with low BMI [24].

Based on the results of his study on 5-to18-year-old individuals, Freedman stated that BMI accuracy as the estimation of body fat mass greatly depended on obesity intensity so that it had high correlation with FMI in children with the BMI more than the 85th percentile and high correlation with fat free mass in children with the BMI less than the 50th percentile. As a result, BMI difference in thin and normal children could arise more from body fat free mass [25]. In Colombo, study agreement between measured BMI and determined FMI based on DXA method was evaluated. The result showed 75% of the underweight subjects had normal FMI. Thirty percent of the subjects who were normal weight based on BMI had high body fat. In overweight subjects, 6.7% had normal FMI and 40% had very high fat mass. This research concluded that there was good agreement between BMI and FMI and moderate agreement between BMI and the body fat percentage and metabolic syndrome risk [22].

The use of FMI, FFMI, and LBMI in children is limited due to a lack of robust reference data [30]. There is an ongoing need to perfect methods that provide information beyond mass and structure (static measures) to kinetic measures that yield information on metabolic and biological functions. On the basis of the wide range of measurable properties, analytical methods and known body composition models, clinicians and scientists can quantify a number of body components and with longitudinal assessment, can track changes in health and disease with implications for understanding efficacy of nutritional and clinical interventions, diagnosis, prevention, and treatment in clinical settings. With the greater need to understand precursors of health risk beginning in childhood, a gap exists in appropriate in-vivo measurement methods beginning at birth [39].

Conclusions

The fact that body mass index represents only a crude proxy for body fat and may produce a significant level of misclassification, but in the absence of alternative measures, the advantages of body mass index have outweighed its disadvantages. However, bio-impedance offers the opportunity to move beyond body mass index. 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. Further studies to elucidate the relationship among BMI, body fatness, fat distribution, and various diseases and health risks in children and adolescents should be followed.

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