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Application of stable isotope dilution techniques to assess body fat and comparison with WHO BMI-for-age classification as a measure of obesity among schoolchildren in Nairobi, Kenya

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Abstract

Objective: WHO BMI-for-age *z* score (BAZ) is widely used in epidemiology, yet it does not distinguish body fat-free mass and fat mass which are better indicators of obesity and related risks. The stable isotope dilution techniques (SIDT) are gold standard methods of assessing body composition. Main objective was to assess significant differences in measurement and validity of WHO BMI-for-age classification for defining childhood obesity by comparing with body fatness using SIDT among schoolchildren.
Design: A cross-sectional analytical study. A questionnaire, anthropometry and body composition data were used. SPSS was used to analyse data at $P < 0{\cdot}05$ at 95 % CI.
Setting: Primary schools in Nairobi City County, Kenya
Participants: One hundred seventy-nine schoolchildren aged 8–11 years were randomly sampled.
Results: Prevalence of adiposity by reference SIDT (24·0 %) was significantly higher than that of obesity by BAZ > 2 SD (2·8 %) (Wilcoxon test, $P < 0{\cdot}05$). Concordance coefficient between SIDT and BAZ > 2 SD in diagnosing obesity was poor ($\kappa = 0{\cdot}167$). Only 11·6 % of children with excess body fat were correctly diagnosed as obese by BAZ > 2 SD. The use of BAZ > 1 SD for overweight and obesity showed fair concordance coefficient ($\kappa = 0{\cdot}409$, $P < 0{\cdot}001$) with 32·5% of children with excess fat positively identified as overweight and obese.
Conclusion: WHO BMI-for-age cut-off points severely underestimate the prevalence of overweight and obesity compared with body composition assessment by stable isotope dilution techniques. Evidence-informed interventions should be based on more accurate estimates of overweight and obesity than that can be provided by BAZ.

Keywords
Obesity
Body fat
BMI-for-age
Stable isotope

The spectrum of nutrition status of children spreads from obesity to severe undernutrition(1). In developing countries, undernutrition among children has been the main concern(2), with the change in lifestyle and dietary practices, most developing countries, Kenya included, are facing the dual burden of malnutrition(3). Ten percentage of the world's school-aged children are estimated to be carrying excess body fat(4) and that the greatest health problems associated with excess body fat will be seen in the next generation of adults as the present childhood obesity epidemic passes through to adulthood(4). Children who are obese have 50–80 % chances of growing up to be obese adults(5). Once a child grows up to be an obese adult, it is difficult to lose weight through diet and physical activity(6,7). Abundant scientific evidence supports the associations between obesity and various diseases, including diabetes mellitus, hypertension, coronary artery disease, cancer and sleep apnoea(8–10). Overweight and obesity have led to a shift in the major causes of death from communicable diseases to a growing burden of modifiable non-communicable diseases(7,11). As such, accurate and reliable indicators are required for early detection or diagnosis of such trends of double burden of malnutrition and for the purpose of monitoring, nutrition intervention and informing policy.

BMI-for-age measurements are the most basic direct and relatively non-invasive methods of assessing nutrition

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status[12]. BMI-for-age is a global proxy of adiposity recommended by WHO for children and adolescent[13]. Application of BMI-for-age indices assumes that differences in body measurements among individuals reflect differences in adiposity and that individuals with identical anthropometric measurements have identical body composition[14]. However, several studies have raised concerns about the performance of anthropometric measurements to correctly identify excess body fatness[10,14,15]. The stable isotope dilution technique (SIDT), also referred to as enrichment technique, is one of the safe, non-radioactive, non-invasive and non-restrictive body composition assessment methods that enable the assessment of body fat mass under free-living conditions[12,16,17]. The SIDT was recommended in the 1990s as a gold standard for measuring body composition; hence, it is considered as a reference method[18], although skinfold measurement is another means of assessing adiposity status and relevant at school age.

The true relation between anthropometric measurements and body fat especially among schoolchildren is not well documented[19]. This has left a dilemma on the accuracy of the commonly used anthropometric measurements to estimate body fat when used in research and clinical practice[20]. Therefore, the current study aimed to establish any significant difference between the two methods and to assess the diagnostic validity of BMI-for-age in assessing obesity among schoolchildren using the percentage of body fat estimated by SIDT as gold standard.

Methods and materials

Design

The study adopted a cross-sectional analytical design.

Setting

The study was conducted in day public schools in Nairobi City County, Kenya.

Participants

Schoolchildren aged 8–11 years from four randomly selected primary schools participated in the study. This age range was considered appropriate for measuring body composition (fat mass (FM) and fat-free mass (FFM)) without adolescence body changes interference.

Sample size determination

The sample size was calculated using Cochran formula: $n_o = Z^2pq/e^2$ for cross-sectional studies. Proportionate to size sampling was used to sample 179 children from the schools. At the school level, stratified random sampling was used to select children from each age groups 8, 9, 10 and 11 years where a representation ratio of boys to girls as 1:1 was anticipated.

Anthropometric measurements

Height was taken with a Holtain stadiometer (Holtain Limited) with the participants standing straight and with no shoes. The height was measured to the nearest 0·1 cm with the eyes of the measurer being at the same level with the headboard. Weight was taken using the electronic scale (Seca model 770; Seca) with participants having light clothing. The readings were taken to the nearest 0·1 kg. The scale was set to zero after every measurement. The scale's accuracy was periodically calibrated using a reference weight. Weight and height measurements were taken three times and the average calculated.

Body fat determination

The current study used ^2H which is a stable (non-radioactive) isotope of H used in body composition assessment. ^2H dose was prepared in the laboratory. The weighing of ^2H was done using an electronic weighing scale which was able to measure up to 0·01 g accuracy.

Preparation and dosing of the participants

Participants were asked to empty the bladder and then they were weighed in light clothing (0·1 kg) as per anthropometry procedures. A baseline saliva sample (4 ml) was then collected from the participants. Each participant was given a ^2H dose which corresponded to their weight to drink using a straw according to International Atomic Energy Agency guidelines[18]. The participants were then given 40 ml of drinking water to rinse the mouth. The time of taking ^2H dose was immediately recorded on the participants' dosage form. The participants waited for 2 h after which the first post-dose saliva sample was collected. The second post-dose saliva sample was collected after another 1 h.

Data analysis

Anthropometric data were analysed using WHO Anthroplus software to determine the BAZ among the study children. WHO standardised cut-off points of >1 SD and greater than +2 SD were used to define overweight and obesity, respectively[13]. Analysis of ^2H enrichment in the saliva samples was performed using Fourier Transform Infrared Spectrometry. Total body water (TBW) was calculated from the dose of ^2H oxide consumed and the concentration of ^2H in saliva, including correction for non-aqueous exchange. Enrichment of ^2H in saliva was measured by Fourier Transform Infrared Spectrometry, and the results were given in mg ^2H_2O/kg H_2O (ppm): TBW (kg) = Dose ^2H_2O (mg)/enrichment ^2H in saliva (mg/kg). The ^2H space is 1·041 times than that of TBW due to the fact that ^2H in body water enters other pools within the body, which is known as non-aqueous exchange, and thus, TBW was calculated as: TBW (kg) = Dose ^2H_2O (mg)/concentration ^2H in saliva (mg/kg)/1·041. Then, FFM (kg) = TBW (kg)/hydration factor. Lohman's hydration factors for children were used.

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FM (kg) = body weight (kg) – FFM (kg). Results were expressed as percentage body weight.

The percentage body fat of >25 % and >30 % was used to define obesity (over fat) for boys and girls, respectively, as used in other studies[21,22]. Cohen's kappa (κ) was used to test for concordance between BAZ and percentage body fat categorisation. The strength of agreement was described as follows: $\kappa = 0{\cdot}20$ as poor, 0·21–0·40 as fair, 0·41–0·60 as moderate, 0·61–0·80 as good and 0·81–1·0 as very good[23]. Body fatness was standardised by expressing FM and FFM in relation to height; thus, this leads to the use of fat mass index (FMI) and fat-free mass index FFMI. There are currently no reference data for FMI for African children, and therefore, we compared our data with the UK reference data[24].

Results

Demographic characteristics of the study children

The mean age was 10·14 ± 0·9 years with close to half (43·6 %) of the pupils being 11 years. The age distribution of the study population is shown in Table 1. The current study included 55·3 % girls and 44·7 % boys. Most of the respondents were in classes (grades) 4 and 5 by Kenyan education system.

Anthropometric and body composition characteristics of the pupils

The mean percentage body fat was 24·0 ± 7·3, while the mean BMI-for-age was 16·2 ± 2·35 (Table 2). There were no significant differences in terms of anthropometric measurements between boys and girls. However, significant differences were observed in the body composition between boys and girls ($P < 0{\cdot}05$) where girls had more body fat compared with boys.

FMI for this study population was 4·0 ± 1·8 and a fat-free mass index of 13·06 ± 4·8. Girls had higher values of both FMI (4·6 ± 1·9) and fat-free mass index (14·38 ± 3·59) compared with boys who had FMI of 3·2 ± 1·5 and fat-free mass index of 11·436 ± 5·7.

Table 1 Demographic characteristics of the study children

Characteristics	*n* (179)	%
Gender		
Boys	80	44·7
Girls	99	55·3
Age (years)		
8	13	7·3
9	27	15·1
10	61	34·1
11	78	43·6
Class/grade		
3	3	1·7
4	30	16·8
4	64	35·8
5	62	34·6
6	20	11·2

Comparison of adiposity by the use of stable isotope dilution techniques and WHO BMI-for-age z scores

Of 179 participants, 43 (24 %) were classified as obese by the use of SIDT compared with 5 (2·8 %) by the use of WHO BMI-for-age *z* scores (Fig. 1). Proportion of children classified as obese by BAZ cut-off points (>2 SD) was significantly lower compared with proportion of children classified as having excess fat by the use of SIDT method (Wilcoxon test, $P < 0{\cdot}05$).

The strength of agreement between the definition of obesity using BAZ >2 SD and SIDT was poor ($\kappa = 0{\cdot}167$, $P < 0{\cdot}001$). Only 11·6 % of the children with excess body fat were correctly identified as obese by the use of BAZ >2 SD. This suggests that BMI-for-age cut-off points >2 SD as recommended by WHO severely underestimate obesity in relation to direct measurements of body fat for this study population.

Further analysis including those who were overweight based on BMI-for-age >1 SD was done to check whether the rates were closer to excess body fat using SIDT. As shown in Fig. 1, the proportion of combined overweight and obesity was (15) 8·4 % which was still significantly lower compared with the proportion of children 43 (24 %) classified as having excess fat by the use of SIDT method (Wilcoxon test, $P < 0{\cdot}05$). The strength of agreement between overweight and obesity (BAZ > 1 SD) and SIDT was fair ($\kappa = 0{\cdot}409$, $P < 0{\cdot}001$) with approximately a third (32·5 %) of children with excess fat being positively identified as overweight and obese by the use of anthropometric method.

Discussion

Methods of assessing direct body composition are expensive and complicated[19,25], and therefore, anthropometric measurements have continued to be used by practitioners in assessing health risks associated with weight. Although obesity means excess body fat, the definition of obesity by the use of BMI-for-age is based on body weight and size regardless of its composition. The major concerns about BMI-for-age measurements are the sensitivity of diagnosing excess body fatness to inform intervention measures[10,14,15]. However, our study findings show a low sensitivity (11·6 %) of BMI-for-age in estimating adiposity and low concordance between BMI-for-age and SIDT in diagnosing excess body fat. Although further analysis using BAZ >1 SD showed a higher sensitivity of 32·5 % compared with when BAZ of >2 SD was used, the strength of agreement between the two methods was still low with more than two-thirds of the participants being classified as

Table 2 Anthropometric and body composition characteristics of the children

	All (n 179)		Boys (n 80)		Girls (n 99)		
Body characteristics	Mean	SD	Mean	SD	Mean	SD	P-values
BMI-for-age	16·17	2·35	16·02	2·14	16·29	2·5	0·442
Mean percentage body fat	24·00	7·3	19·65	5·9	27·52	6·4	<0·001*
Fat mass index	4·0	1·8	3·2	1·5	4·6	1·9	<0·001*
Fat-free mass index	13·06	4·8	11·436	5·7	14·38	3·59	<0·001*

*Significant differences between boys and girls (t test $P<0.05$).

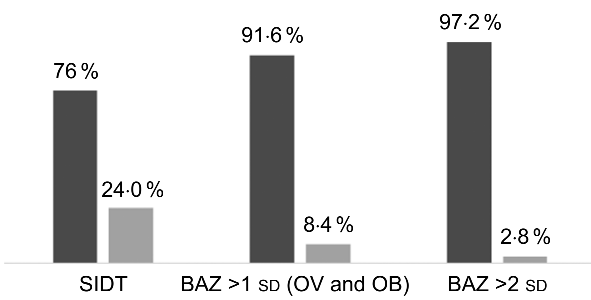

Fig. 1 Comparison of children's adiposity status by the use of stable isotope dilution techniques (SIDT) and BMI-for-age. BAZ, BMI-for-age z scores; OV and OB, overweight and obesity. ■, no excess fat; ■, excess fat

non-obese while they had excess body fat and this have a negative health implication. Although results from the current study suggest that both undernutrition and overnutrition coexisted in this study population using BMI-for-age cut-off point and by the direct measure of body composition using SIDT. However, there was discordance in the classification of nutrition status based on the two methods where BMI-for-age was found to severely underestimate overweight and obesity. The results of the current study suggest that BMI-for-age has limitations to diagnose excess adiposity at the individual level. The inability of BMI-for-age to distinguish fat from lean mass can lead to the inappropriate diagnosis of overweight and obesity. Our study findings indicate more than two-thirds of children who were not labelled as obese actually had excess body fat even though the current study does not provide the evidence for health risks associated with excess adiposity based on the isotope dilution technique at school age.

Showing evidence of inaccurate diagnosing of obesity in individuals indicates a missed opportunity for initiating a lifestyle change in children at risk of health consequences associated with excess body fat. There are no directly comparable studies in African population, but among non-African population, results from the current study concur with other previous studies which have reported a low sensitivity of BMI-for-age in estimating adiposity (36–66 %)[15,22,26]. A review conducted from thirty-two studies reported a low sensitivity (50 %) of anthropometric measurements in assessing body fat, suggesting that about half of individuals not labelled as obese indeed had excess body fat[10]. A study among children in Guatemala found that BMI-for-age does not correspond to the same proportion of body fat[27]. The results from our study confirm and add to the previous cited studies that body measurements by the use of BMI may not always correspond to body fat, and therefore, health practitioners should use anthropometry measurements with caution as a measure of health risk factors associated with weight as even normal weight individuals could have excess body fat. Consistency between the findings of the current study and studies from other populations though not African confirms that underestimation is therefore unlikely to be due to high-percentage body fat secondary to FFM. The use of skinfold measurements in assessing adiposity status at school age could also be explored. The evidence for using the techniques in tracking of school-age overweight/obesity into adulthood as well as the associations for health risks and excess adiposity based on the isotope dilution technique at school age needs to be strengthened. In addition, fat mass index which measures fatness relatively independent of FFM was similar to those of UK children measured in 2001 in the current study using the UK children reference in the 50th percentile[24].

Conclusion

Diagnostic performance of BMI-for-age in assessing nutrition status was poor whereby BAZ severely underestimated the prevalence of overweight and obesity as validated using SIDT used to measure body fat.

Recommendation

Evidence-informed interventions should be based on more accurate estimates of the prevalence of overweight and obesity as provided by direct measure of body fat than that can be provided by BMI-for-age. Since the use of SIDT is expensive and may not be applicable in field set-up, the use of population-specific prediction equations to estimate body fat is an emerging practice as an alternative to the complex methods especially in resource-limited settings. The current study recommends more research in modelling of anthropometric-based prediction equations

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for schoolchildren from body fat data for use to predict excess body fat in case of lack of direct measures of body fat. Longitudinal studies running many decades would be necessary to have childhood body-fatness cut-off points to be based on African population.

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