Body mass index vs deuterium dilution method for establishing childhood obesity prevalence, Ghana, Kenya, Mauritius, Morocco, Namibia, Senegal, Tunisia and United Republic of Tanzania

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Objective To compare the World Health Organization (WHO) body mass index (BMI)-for-age definition of obesity against measured body fatness in African children.

Methods In a prospective multicentre study over 2013 to 2017, we recruited 1516 participants aged 8 to 11 years old from urban areas of eight countries (Ghana, Kenya, Mauritius, Morocco, Namibia, Senegal, Tunisia and United Republic of Tanzania). We measured height and weight and calculated BMI-for-age using WHO standards. We measured body fatness using the deuterium dilution method and defined excessive body fat percentage as > 25% in boys and > 30% in girls. We calculated the sensitivity and specificity of BMI z-score > +2.00 standard deviations (SD) and used receiver operating characteristic analysis and the Youden index to determine the optimal BMI z-score cut-off for classifying excessive fatness.

Findings The prevalence of excessive fatness was over three times higher than BMI-for-age-defined obesity: 29.1% (95% CI: 26.8 to 31.4; 441 children) versus 8.8% (95% CI: 7.5 to 10.4; 134 children). The sensitivity of BMI z-score > +2.00 SD was low (29.7%, 95% CI: 25.5 to 34.2) and specificity was high (99.7%, 95% CI: 99.2 to 99.9). The receiver operating characteristic analysis found that a BMI z-score +0.58 SD would optimize sensitivity, and at this cut-off the area under the curve was 0.86, sensitivity 71.9% (95% CI: 67.4 to 76.0) and specificity 91.1% (95% CI: 89.2 to 92.7).

Conclusion While BMI remains a practical tool for obesity surveillance, it underestimates excessive fatness and this should be considered when planning future African responses to the childhood obesity pandemic.
The aim of this study was to compare the prevalence of the WHO BMI-for-age definition of obesity against the prevalence of excessive body fatness in a relatively large sample of African children.

**Methods**

**Study design**

This design for this prospective, multicentre, data-pooling study, was agreed at the first meeting of the Reducing Obesity Using Nuclear Techniques To Design Interventions study in 2012. We followed the Standards for Reporting of Diagnostic Accuracy Studies15 for the conduct and reporting of the study. Sampling and study procedures originally took place across 11 African centres between 2013 and 2017. We aimed to recruit around 150 participants per country (a larger sample was used in the United Republic of Tanzania, because some of the study aims there required a larger sample). As the nutrition and physical activity transitions in Africa have disproportionately affected urban children,16,17 we focused the sampling in urban areas. In each country, we used a multistage random sampling method to select at least four to five urban public schools in one district or state, followed by school sampling frames of all classes corresponding to the target age group and sex. More details of the methods are available from the corresponding author.

Children meeting the inclusion criteria were recruited to participate in the study after submission of a signed informed consent form by a parent. Data collection was conducted during the school year. Ethical approval was obtained from local research boards or committees in each country. Participants were eligible for inclusion if they were age 8 to 11 years and provided consent or assent for participation; they were excluded if they were outside the study age range, had ill health that would have precluded participation or were not present in school after two consecutive visits.

**Anthropometric measures**

The study used a common protocol and standard operating procedures across all countries. Before data collection started all researchers were trained in data collection methods by a team of experienced researchers and fieldworkers during a 1-week residential course in South Africa. The height of children was measured to the nearest 0.1 cm using a Seca stadiometer, and weight to 0.1 kg in light indoor clothing using a Seca scale (Seca, London, England). From the height and weight measures, we calculated BMI for each child as weight divided by height squared (kg/m²) and then computed age- and sex-specific z-score relative to the WHO BMI-for-age reference18 using the Stata zanthro package (Stata Corp., College Station, United States of America). We defined obesity as BMI z-score > +2.00 SD and overweight (including obesity) as BMI z-score > +1.00 SD.

**Body water measures**

We aimed to measure total body water in all participants using the deuterium dilution method, as described previously.11,14 We used standard operating procedures, with training support provided for all countries via a combination of residential and on-site training by experts recruited by the International Atomic Energy Agency. Ideally, body fatness measurement methods are multicompartment, based on measures of total body water plus body density or total body mineral. However, such methods are laboratory-based and impractical for large-scale epidemiological studies. While not a criterion method, body fatness measured by total body water is practical for large epidemiological studies and provides accurate measures of fatness which are unbiased relative to multicompartment methods.11,12

The total body water measures were made on the same day as the height, weight and waist circumference measures. Accurate measurement of total body water requires a normal hydration status. We therefore asked participants and their families to have normal fluid and food intake on the day before the estimation of total body water and to avoid vigorous exercise after the final meal of the previous day to avoid dehydration and depletion of glycogen stores. Deuterium oxide-labelled water (99.8% purity; Cambridge Isotope Laboratories Inc., Andover, USA) accurately weighed (0.001 g precision) was orally administered to the children according to their body weight (0.5 g deuterium oxide per kg) followed by 50 mL of local tap water. Children were asked not to eat or drink for at least 30 minutes before receiving the deuterium-labelled water and to void their bladders before dosing. Baseline

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**Fig. 1. Flowchart on the inclusion of participants to compare methods to measure overweight in children in eight African countries, 2013–2017**

- 2172 eligible participants recruited and BMI and body composition measured
- Data excluded from 656 participants
  - data not collected or not analysed (155 participants)
  - data rejected by quality control (501 participants)
- Data analysed from 1516 participants
- 1382 participants classified as non-obese by BMI
  - 310 obese by body fatness
  - 1072 non-obese by body fatness
- 134 participants classified as obese by BMI
  - 131 obese by body fatness
  - 3 non-obese by body fatness

BMI: body mass index.

Notes: Children were originally recruited and assessed for BMI and body composition in 11 countries. Data were rejected for quality control reasons from Benin, Mali and Uganda. The final analysis was therefore based on data from eight countries: Ghana, Kenya, Mauritius, Morocco, Namibia, Senegal, Tunisia and United Republic of Tanzania.
Participants were then requested to drink the labelled water dose under supervision and two further saliva samples were collected at 3 hours and 4 hours after the dose using the method described above. All saliva samples were stored at 4 °C until their arrival to the laboratory for storage at −20 °C until analysis. Analysis was carried out with Fourier transform infrared spectroscopy (FTIR 8400S spectrophotometer, Shimadzu Kyoto, Japan) in accordance with International Atomic Energy Agency protocols. We converted measures of total body water to total body fat using equations described in a previous study. The percentage of fat-free mass was calculated as 100 × fat-free mass in kg divided by height in m^2, with fat-free mass measured from total body water. Fat mass index was calculated as fat mass in kg divided by height in m^2, with fat mass measured from total body fat. Fat-free mass index was calculated as fat-free mass in kg divided by height in m^2 and BMI was calculated as weight in kg divided by height in m^2. Z-scores were obtained from the World Health Organization BMI-for-age child growth standards.15

### Table 1. Age and anthropometric characteristics of participants in the study of body mass index-for-age and body fatness among children in eight African countries, 2013–2017

| Sex, by country       | No. (% of children) | Median (IQR) |                  |                  |                  |
|-----------------------|---------------------|--------------|------------------|------------------|------------------|
|                       | Age, years          | BMI z-score  | Body fat percentage | Fat mass index, kg/m^2 | Fat-free mass index, kg/m^2 |
| Ghana                 | 10 (9–11)           | −0.87 (−1.17 to −0.21) | 15.92 (12.57 to 19.94) | 2.37 (1.98 to 2.44) | 12.98 (12.08 to 13.7) |
| Boys                  | 71 (37.4)           |              |                  |                  |                  |
| Girls                 | 119 (62.6)          |              |                  |                  |                  |
| Total                 | 190 (100.0)         |              |                  |                  |                  |
| Kenya                 | 10 (9–11)           | −0.91 (−1.34 to −0.30) | 22.94 (17.93 to 28.61) | 3.58 (2.68 to 5.01) | 12.29 (10.92 to 13.64) |
| Boys                  | 84 (46.9)           |              |                  |                  |                  |
| Girls                 | 95 (53.1)           |              |                  |                  |                  |
| Total                 | 179 (100.0)         |              |                  |                  |                  |
| Mauritius             | 10 (9–11)           | −0.98 (−1.35 to −0.15) | 23.57 (19.34 to 28.11) | 3.64 (2.75 to 4.86) | 12.34 (10.84 to 13.90) |
| Boys                  | 82 (53.6)           |              |                  |                  |                  |
| Girls                 | 71 (46.4)           |              |                  |                  |                  |
| Total                 | 153 (100.0)         |              |                  |                  |                  |
| Morocco               | 9 (8–10)            | 0.20 (−1.00 to 0.51) | 19.76 (16.31 to 24.57) | 3.08 (2.49 to 4.17) | 12.76 (12.15 to 13.6) |
| Boys                  | 94 (50.3)           |              |                  |                  |                  |
| Girls                 | 93 (49.7)           |              |                  |                  |                  |
| Total                 | 187 (100.0)         |              |                  |                  |                  |
| Namibia               | 10 (9–11)           | −0.08 (−0.91 to 0.10) | 22.84 (18.85 to 30.76) | 3.60 (2.70 to 5.73) | 12.92 (12.06 to 13.6) |
| Boys                  | 66 (43.7)           |              |                  |                  |                  |
| Girls                 | 85 (56.3)           |              |                  |                  |                  |
| Total                 | 151 (100.0)         |              |                  |                  |                  |
| Senegal               | 10 (9–11)           | 0.23 (−0.78 to 1.14) | 22.69 (17.43 to 29.60) | 3.59 (2.60 to 5.17) | 12.59 (11.64 to 13.6) |
| Boys                  | 70 (47.9)           |              |                  |                  |                  |
| Girls                 | 76 (52.1)           |              |                  |                  |                  |
| Total                 | 146 (100.0)         |              |                  |                  |                  |
| Tunisia               | 9 (8–10)            | 0.04 (−0.65 to 0.99) | 23.49 (20.30 to 26.86) | 3.86 (3.19 to 5.00) | 12.56 (11.89 to 13.75) |
| Boys                  | 80 (51.0)           |              |                  |                  |                  |
| Girls                 | 77 (49.0)           |              |                  |                  |                  |
| Total                 | 157 (100.0)         |              |                  |                  |                  |
| United Republic of Tanzania | 10 (9–11) | 0.42 (−0.76 to 1.64) | 32.69 (26.76 to 39.06) | 5.38 (4.14 to 8.71) | 11.94 (11.01 to 13.18) |
| Boys                  | 158 (44.8)          |              |                  |                  |                  |
| Girls                 | 195 (55.2)          |              |                  |                  |                  |
| Total                 | 353 (100.0)         |              |                  |                  |                  |
| Total                 | 157 (100.0)         |              |                  |                  |                  |

BMI: body mass index; IQR: interquartile range.

a Number of records removed from original samples: Ghana (4), Kenya (1), Mauritius (3), Morocco (3), Namibia (4), Senegal (10), Tunisia (2) and United Republic of Tanzania (3).

Notes: BMI was calculated as weight in kg divided by height in m^2 and z-scores were obtained from the World Health Organization BMI-for-age child growth standards.15 Body fat percentage was measured using deuterium oxide dilution. Fat mass index was calculated as fat mass in kg divided by height in m^2, with fat mass measured from total body water. Fat-free mass index was calculated as fat free mass in kg divided by height in m^2, with fat-free mass measured from total body water. Measures were made in 2014–2017 in Kenya and United Republic of Tanzania and in 2013–2015 in all other countries.
established age- and sex-specific constants for the hydration of fat-free mass, as described elsewhere. Quality control procedures, with four stringent criteria described in detail elsewhere, were applied to the measures of enrichment of deuterium required for the total body water measures and to the estimates of total body water, total body fat and body fat percentage. These quality control measures were: (i) deuterium enrichment of each of the two post-dose samples should be within 2% of the mean of the two post-dose samples; (ii) measured enrichment should lie within an expected range of normal enrichments based on the body weight of the child (outliers in the total body-water-to-height relationship were identified and excluded); (iii) outliers in body fat percentage were identified and excluded (e.g. large mismatches between body fat percentage and BMI z-score or unphysiological body fat percentage measures); and (iv) if more than 10% of total body water measures from any centre failed to meet the quality control criteria, then we excluded all data from that centre from the pooled analyses. Based on these criteria, we excluded data from three out of 11 original participating countries (Benin, Mali and Uganda), so that the present study is based on data from eight countries (Ghana, Kenya, Mauritius, Morocco, Namibia, Senegal, Tunisia and United Republic of Tanzania) and 1516 children. Among these, 2% of total body water measures were rejected for quality control reasons and were not included in the analyses reported here.

We expressed total body fatness as a percentage of body weight. Many studies have established that a high body fatness, even in childhood, has a range of adverse health consequences, with most focusing on the cardiometabolic consequences, as summarized by systematic reviews. One report on the relationship between body fatness and cardiovascular risk in childhood used a skinfold thickness method previously validated against a multicomponent model to measure body fatness. The researchers found a marked increase in cardiometabolic risk profile at body fat > 23% in boys and > 30% in girls, across a wide age range. We therefore used this definition of excessive fatness (true positive in the receiver operator characteristic analysis) in the present study. As in previous studies, the conclusions were not greatly affected by the definition of excessive fatness (data are available from the corresponding author).

Data management

Training in data management, data sharing and data quality control was provided during a 1-week data management residential training course in Benin in 2014. Throughout the study, support was provided by site visits and online chat or email by a central data management coordinator from Burkina Faso recruited by the International Atomic Energy Agency. The weight and height measures, BMI-for-age z-scores and total body water-derived measures of body fatness were all made prospectively and independently and the results of each measure were not available at the time of the other measures.

Analysis

We used standard diagnostic performance indicators to determine the extent to which BMI z-score > +2.00 SD identified children with excessive fatness. We calculated sensitivity (proportion of real positive values among all the recorded positive values), specificity (proportion of real negative values among all the negative values), and positive and negative predictive values for the total sample. We used the Youden index method to determine the optimal BMI z-score cut-off for optimizing the sensitivity and specificity for identifying excessive fatness. We used Spearman rank-order correlation to test the association between countries’ total BMI-for-age z-score and total body fat percentage. We also made an exploratory analysis of possible geographical differences in the results by grouping the countries into three geographically defined sub-groups: sub-Saharan Africa (Ghana, Kenya, Namibia, Senegal and United Republic of Tanzania), North Africa (Morocco and Tunisia) and an African island (Mauritius).

Results

Fig. 1 shows the flowchart of the study. Of the 2172 children recruited to the study, eligible data were available from 1516 (69.8%). The age and anthropometric characteristics of the eligible participants are shown in Table 1. The mean age was 9.6 years (95% confidence interval, CI: 9.5 to 9.7) and median age was 10 years (interquartile range, IQR: 9 to 11). The median BMI-for-age z-score was −0.35 (IQR: −1.09 to 0.71) and median body fat percentage was 22.65% (IQR: 17.43 to 29.60). Fig. 2 provides more detail on the distribution of body fatness and BMI-for-age z-scores. The prevalence of excessive fatness was 29.1% (95% CI: 26.8 to 31.4; 441 children). Overall, the prevalence of obesity by the WHO BMI-for-age crite-
tion was 8.8% (95% CI: 7.5 to 10.4; 134 children) (Table 2) and of overweight was 19.5% (95% CI: 17.6 to 21.6; 296 children) (Table 3).

In the whole sample, the sensitivity of BMI z-score > +2.00 SD for identifying excessively fat children was 29.7% (95% CI: 25.5 to 34.2), specificity was 99.7% (95% CI: 99.2 to 99.9), positive predictive value 97.8% (95% CI: 93.6 to 99.5) and negative predictive value 77.6% (95% CI: 75.3 to 79.7). The sensitivity of BMI z-score > +2.00 SD to identify excessively fat children varied little between boys and girls (66/203 for boys versus 65/238 for girls). In the whole sample BMI z-score > 1.00 SD had sensitivity of 59.2% (95% CI: 54.4 to 63.8) and specificity of 96.7% (95% CI: 95.5 to 97.7; Table 4). Analysis of the data by country and in the three population sub-groups is shown in Table 2 and Table 3. Sensitivity was lower in the North African and Island populations than the sub-Saharan Africans. The rank order correlation between country median BMI z-score and country fat mass index was high ($r = 0.6$).

The receiver operator characteristic analysis is shown in Fig. 3. The optimal cut-off point in the BMI-for-age distribution for classifying excessive fatness was a BMI z-score of +0.58 SD (Table 4). At this cut-off the area under the curve was 0.86, sensitivity was 71.9% (95% CI: 67.4 to 76.0), specificity was 91.1% (95% CI: 89.2 to 92.7), positive predictive value 76.8% (95% CI: 72.4 to 80.7) and negative predictive value 88.8% (95% CI: 86.7 to 90.6).

**Discussion**

The present study has established the extent to which the WHO BMI-for-age definition of obesity underestimates the prevalence of excessive fatness in African children. Excessive fatness was present in nearly a third of children, suggesting that urban African environments are now highly obesogenic even for children. Excessive fatness was over three times more common than the prevalence of BMI-defined obesity. This difference is large enough to be meaningful for public health. For example, the case for policy action to prevent and control obesity is much weaker at an apparent prevalence of around 8% (based on BMI-for-age z-score > +2.00 SD in the present study) than at the prevalence of around 30% (excessive fatness).

### Table 2. Comparison of obesity defined by body mass index-for-age and by body fatness among children in eight African countries, by geographical area, 2013–2017

| Sub-Saharan Africa | Obesity defined by BMI-for-age | Obesity defined by body fatness, \( \times \) no. (%) of children |
|-------------------|-------------------------------|-------------------------------------------------------------|
| **No** | **Yes** | **Total** |
| **Nigeria** | | |
| No | 183 (100.0) | 5 (71.4) | 188 (99.0) |
| Yes | 0 (0.0) | 2 (28.6) | 2 (1.0) |
| Total | 183 (100.0) | 7 (100.0) | 190 (100.0) |
| **Kenya** | | |
| No | 125 (100.0) | 50 (92.6) | 175 (97.8) |
| Yes | 0 (0.0) | 4 (7.4) | 4 (2.2) |
| Total | 125 (100.0) | 54 (100.0) | 179 (100.0) |
| **Namibia** | | |
| No | 75 (100.0) | 49 (64.5) | 124 (82.1) |
| Yes | 0 (0.0) | 27 (35.5) | 27 (17.9) |
| Total | 75 (100.0) | 76 (100.0) | 151 (100.0) |
| **Senegal** | | |
| No | 130 (100.0) | 12 (75.0) | 142 (97.3) |
| Yes | 0 (0.0) | 4 (25.0) | 4 (2.7) |
| Total | 130 (100.0) | 16 (100.0) | 146 (100.0) |
| **United Republic of Tanzania** | | |
| No | 259 (98.9) | 48 (52.7) | 307 (87.0) |
| Yes | 3 (1.1) | 43 (47.3) | 46 (13.0) |
| Total | 262 (100.0) | 91 (100.0) | 353 (100.0) |
| **North Africa** | | |
| No | 772 (99.6) | 164 (67.2) | 936 (91.9) |
| Yes | 3 (0.4) | 80 (32.8) | 83 (8.1) |
| Total | 775 (100.0) | 244 (100.0) | 1019 (100.0) |
| **Morocco** | | |
| No | 141 (100.0) | 37 (80.4) | 178 (95.2) |
| Yes | 0 (0.0) | 9 (19.6) | 9 (4.8) |
| Total | 141 (100.0) | 46 (100.0) | 187 (100.0) |
| **Tunisia** | | |
| No | 89 (100.0) | 60 (88.2) | 149 (94.9) |
| Yes | 0 (0.0) | 8 (11.8) | 8 (5.1) |
| Total | 89 (100.0) | 68 (100.0) | 157 (100.0) |
| **African island** | | |
| No | 70 (100.0) | 49 (59.0) | 119 (77.8) |
| Yes | 0 (0.0) | 34 (41.0) | 34 (22.2) |
| Total | 70 (100.0) | 83 (100.0) | 153 (100.0) |
| **All countries** | | |
| No | 1072 (99.7) | 310 (70.3) | 1382 (91.2) |
| Yes | 3 (0.3) | 131 (29.7) | 134 (8.8) |
| Total | 1075 (100.0) | 441 (100.0) | 1516 (100.0) |

BMI: body mass index.

1. We measured height and weight and calculated obesity from BMI-for-age using the World Health Organization reference z-score > +2.00 standard deviations.
2. We measured body fatness using the deuterium dilution method and defined excessive body fat percentage as > 25% in boys and > 30% in girls.\footnote{1,12}
Table 3. Comparison of overweight defined by body mass index-for-age and obesity defined by body fatness among children in eight African countries, by geographical area, 2013–2017

| Overweight defined by BMI-for-age | Obesity defined by body fatness, no. (%) of children | Total no. | % (95% CI) |
|----------------------------------|-----------------------------------------------------|-----------|------------|
|                                  | No                                                  | Yes       |             |
| **Sub-Saharan Africa**           |                                                     |           |            |
| Ghana                            | 182 (99.5)                                          | 2 (28.6)  | 184 (96.8) |
| No                               | 1 (0.5)                                             | 5 (71.4)  | 6 (3.2)    |
| Total                            | 183 (100.0)                                         | 7 (100.0) | 190 (100.0)|
| Kenya                            | 122 (97.6)                                          | 48 (88.9) | 170 (95.0) |
| No                               | 3 (2.4)                                             | 6 (11.1)  | 9 (5.0)    |
| Total                            | 125 (100.0)                                         | 54 (100.0)| 179 (100.0)|
| Namibia                          | 75 (100.0)                                          | 26 (34.2) | 101 (66.9) |
| No                               | 0 (0.0)                                             | 50 (65.8) | 50 (33.1)  |
| Total                            | 75 (100.0)                                          | 76 (100.0)| 151 (100.0)|
| Senegal                          | 130 (100.0)                                         | 7 (43.8)  | 137 (93.8) |
| No                               | 0 (0.0)                                             | 9 (56.2)  | 9 (9.2)    |
| Total                            | 130 (100.0)                                         | 16 (100.0)| 146 (100.0)|
| United Republic of Tanzania      |                                                     |           |            |
| No                               | 246 (93.9)                                          | 21 (23.1) | 267 (75.6) |
| Total                            | 16 (6.1)                                            | 70 (76.9) | 86 (24.4)  |
| All                              | 262 (100.0)                                         | 91 (100.0)| 353 (100.0)|
| **North Africa**                 |                                                     |           |            |
| Morocco                          | 137 (97.2)                                          | 21 (45.7) | 158 (84.5) |
| No                               | 4 (2.8)                                             | 25 (54.3) | 29 (15.5)  |
| Total                            | 141 (100.0)                                         | 46 (100.0)| 187 (100.0)|
| Tunisia                          | 84 (94.4)                                           | 29 (42.6) | 113 (72.0) |
| No                               | 5 (5.6)                                             | 39 (57.4) | 44 (28.0)  |
| Total                            | 89 (100.0)                                          | 68 (100.0)| 157 (100.0)|
| All                              | 221 (96.1)                                          | 50 (43.9) | 271 (78.8) |
| No                               | 9 (3.9)                                             | 64 (56.1) | 73 (21.2)  |
| Total                            | 230 (100.0)                                         | 114 (100.0)| 344 (100.0)|
| **African island**               |                                                     |           |            |
| Mauritius                        | 64 (91.4)                                           | 26 (31.3) | 90 (58.8)  |
| No                               | 6 (8.6)                                             | 57 (68.7) | 63 (41.2)  |
| Total                            | 70 (100.0)                                          | 83 (100.0)| 153 (100.0)|
| All countries                    |                                                     |           |            |
| No                               | 1040 (96.7)                                         | 180 (40.8)| 1220 (80.5)|
| Total                            | 35 (3.3)                                            | 261 (59.2)| 296 (19.5) |
| All                              | 1075 (100.0)                                         | 441 (100.0)| 1516 (100.0)|

BMI: body mass index.

a We measured height and weight and calculated overweight from BMI-for-age using the World Health Organization reference z-score > +1.00 standard deviations.1

b We measured body fatness using the deuterium dilution method and defined excessive body fat percentage as >25% in boys and >30% in girls.11,12

Table 4. Comparison of World Health Organization body mass index-for-age cut-offs for obesity and overweight and the empirically determined optimal cut-off for identifying excessive fatness among children in eight African countries, 2013–2017

| Diagnostic performance measure | BMI z-score > +2.00 SD | BMI z-score > +1.00 SD | BMI z-score +0.58 SD |
|--------------------------------|------------------------|------------------------|----------------------|
| No. of children                | Total no.              | % (95% CI)             | Total no.            |
| Sensitivity                    | 131                    | 297 (25.5 to 34.2)     | 261                   |
| Specificity                    | 1072                   | 207 (19.5 to 21.9)     | 296                   |
| Positive predictive value      | 1072                   | 207 (19.5 to 21.9)     | 296                   |
| Negative predictive value      | 1072                   | 207 (19.5 to 21.9)     | 296                   |
| BMI: body mass index; CI: confidence interval; SD: standard deviation.1

a We calculated values as follows: sensitivity: [true positives/(true positives + false negatives])); specificity: [true negatives/(true negatives + false positives)]; positive predictive value: [true positives/(true positives + false positives)]; negative predictive value: [true negatives/(true negatives + false negatives)].

b We calculated the optimal cut-off z-score from the receiver operating characteristic curve (area under the curve 0.86).
observed. To improve the estimation of prevalence, cut-off points in the BMI distribution lower than the z-score of +2.00 SD might be considered. At BMI z-score > +1.00 SD the ability to identify over-fatness was improved but not optimized. The optimal BMI z-score cut-off for classifying excessive fatness (which maximized the area under the curve) in our study was +0.58 SD.

There are no directly comparable studies in African children, or using the WHO-recommended definition based on BMI, but in non-African populations biases have been reported for other BMI-based definitions of obesity. The present study adds to previous studies suggesting that underestimation of excessive fatness by BMI-for-age criteria is likely to be a global cause for concern. Our study shows that a high proportion of African children with apparently healthy BMI-for-age have excessive body fatness. The bias observed is unlikely to be due to a high body fat percentage secondary to unusually low fat-free mass (lean body mass). This is because of the consistency between the findings of the present study and studies for other populations. Furthermore, median fat mass index values, which measure fatness relatively independent of fat-free mass, were high in the present study. Reference data for fat mass index from British children of the same age (and measured in 2001, long after the childhood obesity epidemic had affected children in the United Kingdom of Great Britain and Northern Ireland) were very similar to those in the present study; 50th centile of 3.4 kg/m² for boys and 4.2 kg/m² for girls compared with 3.25 kg/m² for boys and 3.91 kg/m² for girls in the present study. Our findings are consistent with the evidence that body fatness of contemporary children is higher, across the range of body fatness, than that of children in the recent past.

The main strengths of the present study were the large sample size and narrow age range of the sample; the novelty of using the WHO BMI-for-age definition in an African setting; the novelty and value of having an unbiased definition of body fatness; the use of the Standards for Reporting of Diagnostic Accuracy Studies guidance in both the conduct and reporting of the study; and the standardization and quality control of both the study measurement methods and data management. A key limitation of the study was that we were unable to test definitively for differences in the diagnostic accuracy of BMI-for-age across different populations of African children. Our exploratory comparison of country groups by sub-Saharan Africa, North Africa and an island population was underpowered. A further limitation is generalizability. The participant age range of the present study limits our conclusions to 8 to 11 year olds, although our findings are consistent with those reported for younger and older participants, including adults, in systematic reviews of studies from non-African populations.

In conclusion, excessive fatness is now prevalent among urban populations of African children and is likely to have serious future public health implications. While at a group level the BMI z-score and body fatness were related, BMI-for-age substantially underestimated the scale of the problem of excessive fatness and so may hinder or delay future obesity prevention and control efforts in Africa. Further research is needed to determine whether the sensitivity of the BMI-for-age indicator is especially low in African children compared with other populations.

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The results of a study conducted in a group of African children aged 8 to 11 years in urban areas of eight countries (Ghana, Kenya, Morocco, Mauritius, Namibia, Republic of Tanzania, Senegal and Tunisia) showed that the prevalence of overweight and obesity was higher than three times the average in the world. The WHO recommends that children aged 5 to 18 years should have a BMI < 18.5 kg/m² for boys and < 17.5 kg/m² for girls. However, a BMI > 25 kg/m² indicates overweight, and a BMI > 30 kg/m² indicates obesity.

The study used two methods to measure body fat: body mass index (BMI) and deuterium dilution. The BMI is calculated as weight in kilograms divided by height in meters squared, and the deuterium dilution method measures body fat as a percentage of body weight. The study found that the prevalence of overweight and obesity was higher in African children than in children in other parts of the world.

The study also found that the prevalence of overweight and obesity was higher in boys than in girls. The study suggested that a BMI of > 25 kg/m² for boys and > 30 kg/m² for girls could be used to identify children at risk for overweight and obesity.

The study concluded that the prevalence of overweight and obesity in African children is a significant public health issue and that more research is needed to understand the underlying causes and develop effective interventions to prevent and treat these conditions.
était faible (29,7%, IC à 95%: 25,5-34,2), tandis que la spécificité était élevée (99,7%, IC à 95%: 99,2-99,9). L'analyse de la fonction d'efficacité du récepteur a révélé qu'un Z-score de l'IMC de +0,58 ED optimiserait la sensibilité, et qu'à cette valeur limite, l'aire sous la courbe était de 0,86, la sensibilité de 71,9% (IC à 95%: 67,4-76,0) et la spécificité de 91,1% (IC à 95%: 89,2-92,7).

Conclusion Si l'IMC reste est un outil pratique pour surveiller l'obésité, il sous-évalue la masse grasse excessive. Cela doit être pris en compte lors de la planification des futures mesures africaines de lutte contre la pandémie d'obésité chez l'enfant.

Resumen

Índice de masa corporal en comparación con el método de dilución de deuterio para establecer la prevalencia de la obesidad infantil, Ghana, Kenya, Marruecos, Mauricio, Namibia, República Unida de Tanzania, Senegal y Túnez

Objetivo Comparar la definición de obesidad por edad del índice de masa corporal (IMC) de la Organización Mundial de la Salud (OMS) con la grasa corporal medida en niños africanos.

Métodos En un estudio prospectivo multicéntrico realizado entre 2013 y 2017, se reclutaron 1516 participantes de edades comprendidas entre los 8 y los 11 años de zonas urbanas de ocho países (Ghana, Kenya, Marruecos, Mauricio, Namibia, República Unida de Tanzania, Senegal y Túnez). Se midieron altura y peso y calculamos el IMC por edad utilizando los estándares de la OMS. Se midió la grasa corporal mediante el método de dilución de deuterio y se definió el porcentaje de grasa corporal excesiva como > 25% en los niños y > 30% en las niñas. Se calculó la sensibilidad y especificidad del IMC con desviaciones estándar (DE) de los valores Z de > +2,00 y se utilizó el análisis de las características operativas del receptor para determinar el límite óptimo del IMC z-score para clasificar el exceso de grasa.

Resultados La prevalencia de la obesidad excesiva fue más de tres veces superior a la obesidad definida por el IMC por edad: 29,1% (IC del 95%: 26,8 a 31,4; 441 niños) en comparación con un 8,8% (IC del 95%: 7,5 a 10,4; 134 niños). La sensibilidad del IMC con DE de los valores Z > +2,00 fue baja (29,7%, IC del 95%: 25,5 a 34,2) y la especificidad fue alta (99,7%, IC del 95%: 99,2 a 99,9). El análisis de las características operativas del receptor encontró que un IMC z-score +0,58 DE optimizaría la sensibilidad, y en este corte el área bajo la curva era de 0,86, con una especificidad del 71,9% (IC del 95%: 67,4 a 76,0) y una especificidad del 91,1% (IC del 95%: 89,2 a 92,7).

Conclusión Aunque el IMC sigue siendo un medio de medir la obesidad, se recomienda considerar la prevalencia de la obesidad excesiva en la población africana para la monitorización de la obesidad infantil.
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