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Mid-upper arm circumference as a screening tool for identifying children with obesity: a 12-country study

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Summary

Background: No studies have examined if mid-upper arm circumference (MUAC) can be an alternative screening tool for obesity in an international sample of children differing widely in levels of human development.

Objective: Our aim is to determine whether MUAC could be used to identify obesity in children from 12 countries in five major geographic regions of the world.

Methods: This observational, multinational cross-sectional study included 7337 children aged 9–11 years. Anthropometric measurements were objectively assessed, and obesity was defined according to the World Health Organization reference data.

Results: In the total sample, MUAC was strongly correlated with adiposity indicators in both boys and girls ($r > 0.86$, $p < 0.001$). The accuracy level of MUAC for identifying obesity was high in both sexes and across study sites (overall area under the curve of 0.97, sensitivity of 95% and specificity of 90%). The MUAC cut-off value to identify obesity was ~25 cm for both boys and girls. In country-specific analyses, the cut-off value to identify obesity ranged from 23.2 cm (boys in South Africa) to 26.2 cm (girls in the UK).

Conclusions: Results from this 12-country study suggest that MUAC is a simple and accurate measurement that may be used to identify obesity in children aged 9–11 years. MUAC may be a promising screening tool for obesity in resource-limited settings.

Keywords: Adiposity, arm circumference, body mass index, children.

Introduction

Childhood obesity is an important public health issue worldwide and has been associated with a wide range of adverse health risks (1,2). Body mass index (BMI) for age is recommended internationally as a simple measure to identify obesity in children and adolescents (3). However, equipment is generally limited in resource-poor settings, and a more cost-effective and practical alternative to BMI would be helpful. Such an approach may help to increase clinical assessment and public health surveillance of obesity in developing countries where the epidemic of obesity is emerging as well as in isolated locations where stadiometers and scales may be difficult to locate (4). MUAC may also be a useful screening/surveillance tool in settings where measuring weight is deemed inappropriate because of concerns of creating body image issues.

A cost-effective and more practical alternative to BMI could be mid-upper arm circumference (MUAC).

Indeed, MUAC is an easy, quick and inexpensive field measure most commonly used in the assessment of nutritional status (5). Although little is known on the potential for MUAC as a screening tool for obesity in children, recent studies suggest that MUAC can accurately identify overweight and obesity in children (6–8). However, the small sample size and single-location assessment of previous investigations limit the ability to generalize the findings to other areas of the world. The present multinational study is unique in its international, sociocultural and economic diversity and provides an opportunity to determine whether MUAC can be a practical alternative screening measure for obesity in children across countries that differ widely in levels of human development.

The objective of this study was to determine whether MUAC could be used to identify BMI-defined obesity in children from 12 countries representing a wide range of geographic and sociocultural variability. We hypothesized that MUAC could identify BMI-defined obesity with reasonable accuracy in 9- to 11-year-old children around the world and that the accuracy levels would not differ between study sites.

Methods

Setting

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to determine the relationships between lifestyle behaviours and obesity in 12 study sites located in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the UK and the USA. These countries represent a wide range of economic development (low to high income), Human Development Index (0.509 in Kenya to 0.929 in Australia) and inequality (Gini coefficient). The design and methods have been published in detail elsewhere (9). By design, the within-site samples were not intended to be nationally representative. Rather, the primary sampling frame was schools, which was typically stratified by an indicator of socioeconomic status to maximize variability within sites. A standard protocol was used to collect data across all sites, and all study personnel underwent rigorous training and certification before and during data collection to ensure the quality of data collected (9). The Institutional Review Board at the Pennington Biomedical Research Center in Baton Rouge, USA (coordinating centre), approved the ISCOLE protocol, and the institutional/ethical review boards at each participating institution also approved the local protocol. Written informed consent was obtained from parents or legal guardians, and child assent was obtained before participation in the study. Data were collected from September 2011 through December 2013.

Participants

The sample included 9- to 11-year-old children from the 12 ISCOLE sites. The recruitment goal was to enrol a sex-balanced sample of at least 500 children per site, based on an a priori power analysis (9). A total of 7372 children participated in ISCOLE, of whom 7337 remained in the present analytic dataset after excluding participants with missing data. Participants with missing data did not differ in their descriptive characteristics compared with those who were included in the analysis.

Anthropometric measurements

All anthropometric indicators were measured using standard procedures in schools across all study sites (9,10). Body height was measured without shoes using a Seca 213 portable stadiometer (Hamburg, Germany), with the participant's head in the Frankfort horizontal plane. Waist circumference was measured at the end of a gentle expiration with a non-elastic tape held midway between the lower rib margin and the iliac crest (11). MUAC was measured on the right arm using a non-elastic tape held midway between the acromion and the olecranon processes, with arm hanging loosely at the side of the body. Each measurement was repeated, and the average was used for analysis (a third measurement was obtained if the first two measurements were greater than 0.5 cm apart, and the average of the two closest measurements was used for analysis). Body mass and fat mass were measured with a portable Tanita SC-240 scale (Arlington Heights, IL, USA), after all outer clothing, heavy pocket items, shoes and socks were removed. Two measurements were obtained, and the average was used in analysis (a third measurement was obtained if the first two measurements were greater than 0.5 kg or 2.0% apart for body mass and percent body fat, respectively, and the closest two were averaged for analysis). The Tanita SC-240 showed acceptable accuracy for estimating percent body fat when compared with dual-energy X-ray absorptiometry, supporting its use in field studies (12). BMI (kg m^{-2}) was calculated, and BMI z-scores were computed using age-specific and sex-specific reference data from the World Health Organization (3). Participants were classified as obese [BMI z-score $> +2$ standard deviation {SD}] or non-obese (BMI z-score $\leq +2$ SD).

Statistical analysis

Statistical analyses were conducted using R version 3.2.2 (The R Foundation for Statistical Computing, Vienna, Austria) and JMP version 12 (SAS Institute, Cary, NC, USA). Means and SDs of descriptive characteristics were computed by sex for participants with complete measurements. Differences between boys and girls were determined using unpaired *t*-tests for continuous variables and chi-squared tests for categorical variables. Pearson correlation coefficients were calculated to determine the strength of the linear relationship between MUAC and other adiposity indicators. Receiver operating characteristic (ROC) curves were used to select thresholds of MUAC associated with obesity (13). The area under the curve (AUC) is considered a measure of the use of the predictor variable and represents the trade-off between the correct identification of high-risk (obese) individuals (sensitivity) and the correct identification of low-risk (non-obese) individuals (specificity). An AUC of 1 indicates the ability to perfectly distinguish between obese and non-obese participants, whereas an AUC of 0.5 indicates no greater predictive ability than chance alone. The categories used to summarize accuracy in ROC analysis were as follows: excellent (0.9–1), good (0.8–0.9), fair (0.7–0.8), poor (0.6–0.7) and fail (0.5–0.6) (8). A test with an AUC ≥0.85 is generally considered an accurate test (14). The optimal threshold was determined from the Youden index (15), which is the maximum value of J:

$$J = \text{sensitivity} + \text{specificity} - 1.$$

Statistical significance of differences in AUCs between sites was assessed by using the non-parametric approach of DeLong *et al.* (16). As an additional sensitivity analysis, we reanalysed the data after reclassifying the participants as obese and non-obese using the International Obesity Task Force thresholds (17) as well as the Centers for Disease Control and Prevention thresholds (18). Where appropriate, Bonferonni corrections were made to account for multiple group comparisons.

Results

Descriptive characteristics of the sample are shown in Table 1. Overall, boys and girls did not significantly differ in mean height, body mass or BMI; however, percent body fat was significantly higher in girls, and a larger proportion of boys were identified as obese by their BMI *z*-scores (15.5% vs. 10.1% for boys and girls, respectively).

Table 2 presents the Pearson correlation coefficients between MUAC and anthropometric variables for boys and girls. MUAC was strongly correlated with body mass, BMI, BMI *z*-score, percent body fat and waist circumference in both boys and girls ($r \geq 0.86$, $p < 0.001$). These strong correlation coefficients were seen for both boys and girls and in all 12 study sites (data not shown).

The results of the ROC curve analyses are presented in Table 3. AUC results were excellent for boys and girls (0.98 and 0.97, respectively). Sensitivity and specificity were high for both sexes (90–95%). The MUAC cut-off to identify BMI-defined obesity was ~25 cm for both boys and girls. In country-specific analyses (Tables S1–S3), results were very similar across sites. In the total sample, the ROC-AUC for MUAC predicting obesity ranged between 0.94 (UK) and 0.99 (Kenya and China), while

Table 1 Descriptive characteristics of participants stratified by sex ($N = 7337$)

	Boys ($N = 3408$)	Girls ($N = 3929$)	p
Age (year)	10.5 (0.6)	10.4 (0.6)	<0.001
Height (cm)	141.6 (7.4)	141.8 (7.8)	0.25
Body mass (kg)	37.5 (9.7)	37.4 (9.5)	0.79
BMI (kg m^{-2})	18.5 (3.5)	18.4 (3.5)	0.39
BMI *z*-score*	0.57 (1.32)	0.41 (1.21)	<0.001
Body fat (%)	19.0 (7.4)	22.6 (7.6)	<0.001
Waist circumference (cm)	64.9 (9.5)	63.8 (8.7)	<0.001
MUAC (cm)	22.0 (3.5)	22.2 (3.4)	<0.01
Obesity (%)†	15.5	10.1	<0.001

Data are shown as mean (SD) unless otherwise indicated.
Mean differences between sexes were tested using unpaired *t*-test for continuous variables and a chi-squared test for obesity.
*BMI *z*-score computed from World Health Organization growth reference (3).
†Obesity defined according to the World Health Organization criteria (3).
BMI, body mass index; MUAC, mid-upper arm circumference; SD, standard deviation.

Table 2 Relationship between mid-upper arm circumference and other anthropometric indicators by sex ($N = 7337$)

	Boys ($N = 3408$)		Girls ($N = 3929$)	
	r	p	r	p
Height (cm)	0.53	<0.001	0.47	<0.001
Body mass (kg)	0.92	<0.001	0.90	<0.001
BMI (kg m^{-2})	0.94	<0.001	0.93	<0.001
BMI *z*-score*	0.92	<0.001	0.90	<0.001
Body fat (%)	0.86	<0.001	0.88	<0.001
Waist circumference (cm)	0.91	<0.001	0.87	<0.001

Pearson product–moment correlation coefficients were computed to determine the strength of the associations between mid-upper arm circumference and other anthropometric indicators.
BMI, body mass index.
*BMI *z*-score computed from World Health Organization growth reference (3).

the optimal MUAC cut-offs to identify obesity were between 23.5 cm (South Africa) and 25.7 cm (UK). Sensitivity values were between 92% (UK) and 99% (Canada), while specificity values were between 88% (India) and 96% (Kenya and China). In sensitivity analyses conducted using the International Obesity Task Force and Centers for Disease Control and Prevention definitions of obesity, the findings of ROC curve analyses for the association between MUAC and obesity were similar (Tables S4 and S5).

Discussion

The present study was the first to examine if MUAC can be a useful, alternative and practical screening tool for obesity in an international sample of children differing widely in levels of human development. Findings from this study revealed that the simple and inexpensive MUAC is an accurate measure to identify obesity in school children aged 9–11 years. Overall AUC results of 0.97 are consistent with robust diagnostic performance and indicate that measurement of MUAC has a powerful ability to identify children who are classified as obese/non-obese by their BMI *z*-scores, an accepted criterion for obesity and its associated cardiometabolic risk factors (19,20). The consistency of results obtained from applying other BMI-based definitions of obesity is also encouraging and reinforces the applicability of our findings. Thus, MUAC may have potential as a clinical and surveillance indicator of obesity in children, especially in resource-poor or isolated settings.

Results of this study are consistent with previous investigations. Mazıcıoğlu *et al.* (6) reported an AUC of 0.94 and 0.89 for boys and girls, respectively, for 10-year-old Turkish children (MUAC vs. overweight/obesity). Likewise, Lu *et al.* (7) found AUC values ranging between 0.93 and 0.98 for MUAC predicting overweight/obesity in a sample of Han children aged 7–12 years. Finally, Craig *et al.* (8) showed ROC-AUC values between 0.90 and 0.97 for MUAC predicting overweight/obesity in a sample of Black South African children and adolescents aged 5–14 years. The optimal MUAC cut-off values to identify overweight/obesity ranged between 18.1 and 25.7 cm depending on age (age ranged between 5 and 17 years in previous studies). Of note, we only used BMI-defined obesity as an outcome measure in the present study because it is the body-weight category most commonly associated with adverse health risks (2). In our study, a cut-off value of 25 cm seems to be highly accurate in identifying 9- to 11-year-old children with BMI-defined obesity around the world.

Although MUAC is widely used as an indicator of severe and moderately acute undernutrition (5), the present study provides good evidence that MUAC may also be an accurate indicator of obesity in children. This finding may be particularly useful in resource-poor settings (such as Kenya, India and Colombia) where a double burden of disease co-exists (undernutrition and overnutrition). Traffic light colours of red (obese), amber (overweight) and green (normal weight) may also be considered by non-numerate field workers in developing countries to facilitate screening. A MUAC >25 cm in 9- to 11-

Table 3 Results of ROC curve analyses for the association between mid-upper arm circumference and obesity in children

	AUC (95% CI)*	Youden index	Threshold, cm (95% CI)	Sensitivity, % (95% CI)	Specificity, % (95% CI)
Boys ($N = 3408$)	0.98 (0.98–0.99)	0.87	24.6 (24.3–25.0)	95 (92–97)	92 (90–94)
Girls ($N = 3929$)	0.97 (0.96–0.98)	0.84	25.2 (24.8–25.6)	94 (92–97)	90 (87–92)
Total ($N = 7337$)	0.97 (0.97–0.98)	0.84	24.8 (24.4–25.3)	95 (91–97)	90 (87–93)

*Obesity defined according to the World Health Organization criteria (3).
AUC, area under the curve; CI, confidence interval; ROC, receiver operating characteristic.

year-old children may serve as a practical screening tool to identify children with obesity in clinical practice and for surveillance purposes. Replication studies need to be conducted with other age groups to determine optimal MUAC thresholds. Adjustments may also be necessary for pubertal development in older children given that maturation can impact body composition and, therefore, the interpretation of results. Future studies should also relate MUAC to functional outcomes, i.e. the development of comorbidities associated with obesity such as type 2 diabetes and cardiovascular disease and the presence of their risk factors.

This study has several strengths and limitations that warrant discussion. An important strength is the large multinational sample of children from low-income to high-income countries across several regions of the world. We also used a highly standardized measurement protocol, the use of objective measurements and a rigorous quality control programme to ensure high quality data across all sites (9). However, our results need to be interpreted in light of the following limitations. First, ISCOLE was not designed to provide nationally representative data, and therefore, the degree to which the results are generalizable is not known. Second, the present results were based on a sample of 9- to 11-year-old children. Future studies should validate the optimal MUAC cut-offs in representative samples of children from around the world spanning a larger age range and ethnic groups. Another alternative would be to use the arm-to-height ratio (calculated as the arm circumference/height), a non-age-dependent index of adiposity. However, the correlation between arm-to-height ratio and adiposity indicators has been shown to be weaker than with the use of MUAC (7). Furthermore, a stadiometer would be required, and therefore, the tool would become less practical. Finally, longitudinal studies will be needed to associate MUAC with not only obesity but also with incidence of its associated comorbidities.

Conclusions

The present study provides evidence that the inexpensive and practical MUAC measurement is an accurate index for identifying BMI-defined obesity in 9- to 11-year-old children across countries that vary widely in economic and epidemiological transition. Specifically, a MUAC cut-off of 25 cm, which correctly identified boys and girls with obesity with a high level of accuracy, could be used as a reference for school children aged 9–11 years. Future work should expand to other age groups and assess functional outcomes (i.e. health risks) of a high MUAC in low-income, middle-income and high-income countries.

Conflict of interest statement

M. F. has received a research grant from Fazer Finland and has received an honorarium for speaking for Merck. A. K. has been a member of the Advisory Boards of Dupont and McCain Foods. R. K. has received a research grant from Abbott Nutrition Research and Development. V. M. is a member of the Scientific Advisory Board of Actigraph and has received an honorarium for speaking for The Coca-Cola Company. T. O. has received an honorarium for speaking for The Coca-Cola Company. The authors reported no other potential conflicts of interest.

Author contributions

Chaput, Katzmarzyk, Barnes, Fogelholm, Hu, Kuriyan, Kurpad, Lambert, Maher, Maia, Matsudo, Olds, Onywera, Sarmiento, Standage, Tudor-Locke, Zhao and Tremblay conceptualized and designed the study. Acquisition of data was by Chaput, Katzmarzyk, Barnes, Fogelholm, Hu, Kuriyan, Kurpad, Lambert, Maher, Maia, Matsudo, Olds, Onywera, Sarmiento, Standage, Tudor-Locke, Zhao and Tremblay. Chaput, Katzmarzyk, Barnes and Tremblay analysed and interpreted the data. Chaput drafted the manuscript. Chaput, Katzmarzyk, Barnes, Fogelholm, Hu, Kuriyan, Kurpad, Lambert, Maher, Maia, Matsudo, Olds, Onywera, Sarmiento, Standage, Tudor-Locke, Zhao and Tremblay critically revised the manuscript for important intellectual content. Katzmarzyk obtained funding.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Results of the receiver operating characteristic (ROC) curve analyses for the association between mid-upper arm circumference and obesity in ***boys*** stratified by country (WHO definition of obesity).

Table S2. Results of the receiver operating characteristic (ROC) curve analyses for the association between mid-upper arm circumference and obesity in ***girls*** stratified by country (WHO definition of obesity).

Table S3. Results of the receiver operating characteristic (ROC) curve analyses for the association between mid-upper arm circumference and obesity in the ***total sample*** stratified by country (WHO definition of obesity).

Table S4. Results of receiver operating characteristic (ROC) curve analyses for the association between mid-upper arm circumference and obesity in children (IOTF definition of obesity).

Table S5. Results of receiver operating characteristic (ROC) curve analyses for the association between mid-upper arm circumference and obesity in children (CDC definition of obesity).