International Journal of Obesity Supplements (2015) 5, S43–S46

www.nature.com/ijosup

SHORT COMMUNICATION

Association between body mass index and body fat in 9–11-year-old children from countries spanning a range of human development

PT Katzmarzyk[1], TV Barreira[1,2], ST Broyles[1], J-P Chaput[3], M Fogelholm[4], G Hu[1], R Kuriyan[5], A Kurpad[5], EV Lambert[6], C Maher[7], J Maia[8], V Matsudo[9], T Olds[7], V Onywera[10], OL Sarmiento[11], M Standage[12], MS Tremblay[3], C Tudor-Locke[1,13], P Zhao[14] and TS Church[1] for the ISCOLE Research Group

The purpose was to assess associations between body mass index (BMI) and body fat in a multinational sample of 9–11-year-old children. The sample included 7265 children from countries ranging in human development. Total body fat (TBF) and percentage body fat (PBF) were measured with a Tanita SC-240 scale and BMI *z*-scores (BMIz) and percentiles were computed using reference data from the World Health Organization and the U.S. Centers for Disease Control and Prevention, respectively. Mean PBF at BMIz values of −1, 0 and +1 were estimated using multilevel models. Correlations between BMI and TBF were >0.90 in all countries, and correlations between BMI and PBF ranged from 0.76 to 0.96. Boys from India had higher PBF than boys from several other countries at all levels of BMIz. Kenyan girls had lower levels of PBF than girls from several other countries at all levels of BMIz. Boys and girls from Colombia had higher values of PBF at BMIz = −1, whereas Colombian boys at BMIz 0 and +1 also had higher values of PBF than boys in other countries. Our results show a consistently high correlation between BMI and adiposity in children from countries representing a wide range of human development.

International Journal of Obesity Supplements (2015) 5, S43–S46; doi:10.1038/ijosup.2015.18

INTRODUCTION

Body mass index (BMI) is the most widely used marker of obesity in both children and adults. Although BMI cannot differentiate between lean and fat tissue, it is correlated with more direct markers of adiposity across the lifespan.[1–4] Further, BMI has been shown to be a good indicator of excess adiposity in children,[5,6] although there is evidence of moderate heterogeneity in its clinical usefulness, largely explained by differences in race, obesity definition and type of reference data.[7] Most research to date on the association between BMI and body fat has been conducted in high-income countries, and there is a paucity of data on associations among children from low- and middle-income countries. The purpose of this study was to assess the associations between BMI and adiposity in a sample of 9–11-year-old children from countries spanning a wide range of socioeconomic status and human development, and to test for differences in the associations between countries.

MATERIALS AND METHODS

The sample included a total of 7265 children 9–11 years of age (3883 girls) from sites in 12 countries (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the United Kingdom and the United States).[8] The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) protocol was approved by the Institutional Review Board at the Pennington Biomedical Research Center (Coordinating Center) as well as the Ethical Review Boards at each participating institution. Written informed consent was obtained from parents or legal guardians, and child assent was also obtained before participation in the study as required by local Ethical Review Boards.

Body mass and percentage body fat (PBF; %) were measured with a Tanita SC-240 scale (TANITA Corporation, Tokyo, Japan) after all outer clothing, heavy pocket items and shoes were removed. Total body fat (TBF; kg) was computed by multiplying the body fat percentage by body mass. Body height (cm) was measured without shoes using a Seca 213 portable stadiometer (Hamburg, Germany), with the head in the Frankfort plane. Each measurement was repeated and the average was used for analysis (a third measurement was obtained if the first two measurements were >0.5 cm apart for body height, 0.5 kg apart for body mass and 2.0% for PBF, respectively, and the average of the two closest measurements was used in analyses). BMI was calculated (weight (kg)/height (m^2)) and age- and sex-specific *z*-scores (BMIz) were computed using the reference data from the World Health Organization (WHO).[9] Further, age- and sex-specific BMI percentiles (%iles) were computed using the reference data from the US Centers for Disease Control and Prevention (CDC).[10]

[1]Pennington Biomedical Research Center, Baton Rouge, LA, USA; [2]Department of Exercise Science, University of Syracuse, Syracuse, NY, USA; [3]Children's Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada; [4]Department of Food and Environmental Sciences, University of Helsinki, Helsinki, Finland; [5]St Johns Research Institute, Bangalore, India; [6]Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town, South Africa; [7]Alliance for Research in Exercise Nutrition and Activity (ARENA), School of Health Sciences, University of South Australia, Adelaide, South Australia, Australia; [8]CIFI2D, Faculdade de Desporto, University of Porto, Porto, Portugal; [9]Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul, Sao Paulo, Brazil; [10]Department of Recreation Management and Exercise Science, Kenyatta University, Nairobi, Kenya; [11]School of Medicine, Universidad de los Andes, Bogota, Colombia; [12]Department for Health, University of Bath, Bath, UK; [13]Department of Kinesiology, University of Massachusetts Amherst, Amherst, MA, USA and [14]Tianjin Women's and Children's Health Center, Tianjin, China. Correspondence: Dr PT Katzmarzyk, Pennington Biomedical Research Center, 6400 Perkins Road, Baton Rouge, 70808-4124 LA, USA.
E-mail: Peter.Katzmarzyk@pbrc.edu

The associations between BMI, WHO BMIz, CDC BMI %ile, and PBF and TBF were estimated using Pearson correlations. Given that the primary sampling frame of ISCOLE was schools, nested within sites, multilevel mixed models were used to estimate the mean PBF at WHO BMIz scores of −1, 0 and +1 in boys and girls separately. A BMIz-by-site interaction term was included to determine whether the association differed across sites. Pairwise differences across countries were tested using a Bonferroni correction for multiple comparisons. SAS version 9.4 (SAS Institute, Cary, NC, USA) was used for all analyses.

RESULTS

The mean (s.d.) values for age and BMI were 10.4 (0.6) years and 18.5 (3.5) kg m^{-2}, respectively, and the mean CDC BMI %ile was 57.3 (30.3) and WHO BMIz was 0.48 (1.26). The corresponding means for PBF and TBF were 21.0 (7.7) % and 8.4 (5.4) kg, respectively. Table 1 presents correlations among the BMI variables and TBF and PBF across all ISCOLE research sites. The correlations between BMI and TBF were consistently above 0.90 in all 12 countries, and the correlations between BMI and PBF were between 0.76 and 0.96. Thus, BMI and bioelectrical impedance-derived estimates of body fat were highly correlated across all ISCOLE sites.

Figure 1 presents the mean levels of PBF in boys and girls at WHO BMIz of −1, 0 and +1. The interaction between WHO BMIz and site in the multilevel model was significant ($P < 0.001$) in both boys and girls. It is clear that absolute level of PBF increases across levels of WHO BMIz in both boys and girls. Across all countries combined: BMIz = −1 corresponds to a PBF of 10.5% in boys and 15.0% in girls; BMIz = 0 corresponds to a PBF of 15.9% in boys and 20.4% in girls; and BMIz = +1 corresponds to PBF of 21.2% in boys and 25.7% in girls. As indicated in the figure legend, there were several significant differences in PBF at a given level of WHO BMIz across sites. In particular, boys from India had significantly higher PBF than boys from several other countries at all levels of WHO BMIz. Further, Kenyan girls had significantly lower levels of PBF than girls from several other countries at all levels of BMI, especially at WHO BMIz values of 0 and +1. Both boys and girls from Colombia had higher values of PBF at WHO BMIz = −1 than those in some other countries, whereas Colombian boys at WHO BMIz 0 and +1 also had higher values of PBF than boys in some other countries. In boys, the largest mean differences between countries were 4.7% between India and Portugal at BMIZ = −1, 3.9% between India and Portugal at BMIz = 0, and 3.4% at BMIz = +1 between India and Kenya. In girls, the largest mean differences between countries were 3.7% between India and Kenya at BMIZ = −1, 4.1% between India and Kenya at BMIz = 0 and 4.4% at BMIz = +1 between India and Kenya. Overall, 92% of the comparisons between countries were within 3% PBF and 81% were within 2% PBF.

DISCUSSION

Our results show a consistently high correlation between BMI and adiposity assessed using bioelectrical impedance in children from 12 countries representing a wide range of socioeconomic status and human development. Statistically significant mean differences exist across countries in the level of PBF for a given level of BMI; with the maximal differences observed between countries being $< 5\%$ PBF. In all cases, the highest level of PBF at each level of WHO BMIz was in Indian children, and the lowest was in children from Portugal or Kenya.

These results support previous studies that have documented strong associations between BMI and adiposity in children. For example, Pietrobelli *et al.*[3] reported R^2 values of 0.85 and 0.89 for the association between BMI and TBF measured by dual-energy X-ray absorptiometry in a sample of 5–19-year-old Italian boys and girls, respectively. An analysis of the data from 6–11-year-old children from the US National Health and Nutrition Examination Survey reported correlations of 0.81 and 0.88 between BMI-for-age and PBF and correlations of 0.77 and 0.82 between BMI-for-age and TBF in boys and girls, respectively.[4] These results are similar to ours, where the overall (total sample) correlation is 0.81 between CDC BMI %ile and PBF and 0.76 between CDC BMI %ile and TBF. Similarly, the Pearson correlations of BMI with PBF and TBF were 0.83 and 0.93, respectively, in a sample of 3–12-year-old children from New York City (White, African American, Chinese and Korean) and China.[11] In that study, for a given level of BMI, Asians (from China and Korea) had higher levels of PBF than White and African Americans. In our study, we found that boys from India had significantly higher PBF than boys in several other countries, but Chinese boys and girls did not stand out as being different than children from other counties. The results for Colombia may partially be a reflection of altered relationships between BMI and body composition associated with the double burden of malnutrition.[12]

Table 1. Pearson correlations between BMI and adiposity variables among boys and girls from the International Study of Childhood Obesity, Lifestyle and the Environment

	Australia	*Brazil*	*Canada*	*China*	*Colombia*	*Finland*	*India*	*Kenya*	*Portugal*	*South Africa*	*United Kingdom*	*United States*
Boys												
BMI–TBF	0.94	0.96	0.96	0.97	0.94	0.93	0.96	0.92	0.95	0.95	0.94	0.97
BMI–PBF	0.87	0.95	0.93	0.94	0.87	0.88	0.93	0.86	0.93	0.88	0.90	0.94
WHO BMIz–TBF	0.88	0.85	0.87	0.91	0.87	0.81	0.89	0.82	0.89	0.86	0.86	0.88
WHO BMIz–PBF	0.86	0.91	0.90	0.94	0.86	0.83	0.91	0.78	0.90	0.85	0.87	0.91
CDC BMI %ile–TBF	0.77	0.68	0.72	0.79	0.81	0.69	0.84	0.74	0.77	0.76	0.75	0.66
CDC BMI %ile–PBF	0.79	0.78	0.80	0.86	0.81	0.75	0.88	0.71	0.81	0.79	0.79	0.75
Girls												
BMI–TBF	0.97	0.97	0.97	0.98	0.96	0.96	0.97	0.90	0.97	0.97	0.96	0.98
BMI–PBF	0.94	0.95	0.95	0.95	0.93	0.91	0.95	0.76	0.96	0.94	0.95	0.96
WHO BMIz–TBF	0.89	0.88	0.92	0.91	0.90	0.90	0.92	0.82	0.91	0.89	0.91	0.89
WHO BMIz–PBF	0.93	0.95	0.95	0.95	0.92	0.91	0.95	0.74	0.95	0.92	0.92	0.95
CDC BMI %ile–TBF	0.79	0.74	0.86	0.84	0.87	0.87	0.87	0.76	0.81	0.81	0.86	0.76
CDC BMI %ile–PBF	0.87	0.87	0.92	0.92	0.91	0.89	0.93	0.71	0.89	0.87	0.91	0.88

Abbreviations: BMI, body mass index; BMIz, BMI *z*-score; CDC, Centers for Disease Control and Prevention; PBF, percentage body fat; TBF, total body fat; WHO, World Health Organization.

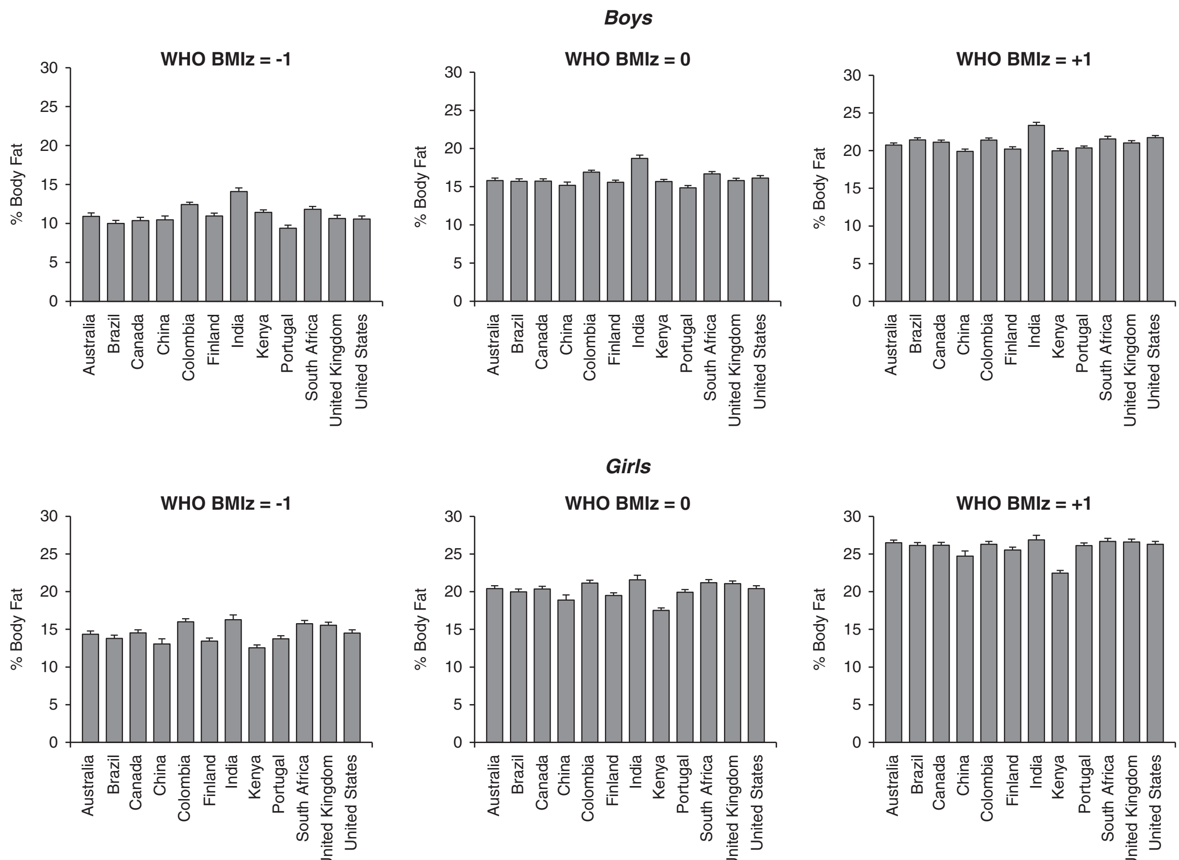

Figure 1. Levels of percentage body fat (PBF) at WHO BMIz values of − 1, 0 and 1 in 7265 (**a**) boys and (**b**) girls from the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE). Error bars represent s.e. WHO BMIz computed from reference data from the World Health Organization.[9] Significant differences in boys: at WHO BMIz = − 1: Colombia > Canada, China, Portugal; India > Canada, China, Finland, Kenya, Portugal, South Africa, the United Kingdom and the United States; Portugal < Colombia, Kenya, India and South Africa; at WHO BMIz = 0: Colombia > China, Finland and Portugal; India > Australia, Brazil, Canada, China, Colombia, Finland, Kenya, Portugal, the United Kingdom and the United States; Portugal < South Africa, Colombia and India; at WHO BMIz = +1: Colombia > Kenya; India > Australia, Brazil, Canada, China, Colombia, Finland, Kenya, Portugal and the United Kingdom; the United States > China, Finland, Portugal and Kenya; Brazil > Kenya. Significant differences in girls: at WHO BMIz = − 1: Kenya < Canada, Colombia, India, South Africa, the United Kingdom and the United States; Colombia > Brazil, China, Finland, Kenya, and Portugal; Finland < Colombia, India, South Africa and the United Kingdom; India > China and Finland; South Africa > Kenya, Finland and Portugal; at WHO BMIz = 0: Kenya < Australia, Brazil, Canada, Colombia, Finland, India, Portugal, South Africa and the United States; at WHO BMIz = +1: Kenya < Australia, Brazil, Canada, Colombia, Finland, India, Portugal, South Africa, the United Kingdom and the United States.

This study has several strengths and some limitations. The large sample of boys and girls from sites in 12 countries spanning the entire globe is a marked strength, as is the standardized methodology to directly measure height and weight. We have identified children by their country of residence, and we were not able to control for ethnic or racial differences within and between countries given the wide range of ethnicities represented in the sample and the diverse ways that they are classified from country to country. We previously conducted a validation study of the Tanita SC-240 scale among White and African American children and the results demonstrated that the scale had acceptable accuracy for estimating PBF in field studies.[13] However, the degree to which the validity of the scale varied across sites and may have impacted the results is not known. Each BIA device uses proprietary equations to estimate body fat, and this may impact the level of adiposity obtained with each device; however, this is unlikely to impact the comparisons among countries given that the same scale was used at all research sites.

In summary, our results demonstrate that BMI is highly correlated ($r > 0.90$) with bioelectrical impedance measures of adiposity in 9–11-year-old children from countries spanning a wide range of socioeconomic status and human development. There were several significant differences in the mean level of PBF at a given level of WHO BMIz among countries, which suggests that caution should be used when using specific BMI thresholds to identify the risk of obesity-related comorbidities in multinational studies. Further research is required to determine whether ethnic-specific BMI categories will improve the discrimination of obesity-related health risks in children.

CONFLICT OF INTEREST

MF has received a research grant from Fazer Finland and has received an honorarium for speaking for Merck. AK has been a member of the Advisory Boards of Dupont and McCain Foods. RK has received a research grant from Abbott Nutrition Research and Development. VM is a member of the Scientific Advisory Board of Actigraph and has received an honorarium for speaking for The Coca-Cola Company. TO has received an honorarium for speaking for The Coca-Cola Company. The remaining authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank the ISCOLE External Advisory Board and the ISCOLE participants and their families who made this study possible. A membership list of the ISCOLE Research

Group and External Advisory Board is included in Katzmarzyk *et al.* (this issue). ISCOLE was funded by The Coca-Cola Company.

REFERENCES

1 Bouchard C. BMI, fat mass, abdominal adiposity and visceral fat: where is the 'beef'? *Int J Obes (Lond)* 2007; **31**: 1552–1553.
2 Katzmarzyk PT, Bouchard C. Where is the beef? Waist circumference is more highly correlated with BMI and total body fat than with abdominal visceral fat in children. *Int J Obes (Lond)* 2014; **38**: 753–754.
3 Pietrobelli A, Faith MS, Allison DB, Gallagher D, Chiumello G, Heymsfield SB. Body mass index as a measure of adiposity among children and adolescents: a validation study. *J Pediatr* 1998; **132**: 204–210.
4 Mei Z, Grummer-Strawn LM, Pietrobelli A, Goulding A, Goran MI, Dietz WH. Validity of body mass index compared with other body-composition screening indexes for the assessment of body fatness in children and adolescents. *Am J Clin Nutr* 2002; **75**: 978–985.
5 Freedman DS, Sherry B. The validity of BMI as an indicator of body fatness and risk among children. *Pediatrics* 2009; **124** (Suppl 1): S23–S34.
6 Freedman DS, Wang J, Maynard LM, Thornton JC, Mei Z, Pierson RN *et al*. Relation of BMI to fat and fat-free mass among children and adolescents. *Int J Obes (Lond)* 2005; **29**: 1–8.
7 Javed A, Jumean M, Murad MH, Okorodudu D, Kumar S, Somers VK *et al*. Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis. *Pediatr Obes* 2014; **10**: 234–244.
8 Katzmarzyk PT, Barreira TV, Broyles ST, Champagne CM, Chaput JP, Fogelholm M *et al*. The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE): design and methods. *BMC Public Health* 2013; **13**: 900.
9 De Onis M, Onyanga AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007; **85**: 660–667.
10 Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z *et al*. 2000 CDC Growth Charts for the United States: methods and development. *Vital Health Stat 11* 2002; **246**: 1–190.
11 Navder KP, He Q, Zhang X, He S, Gong L, Sun Y *et al*. Relationship between body mass index and adiposity in prepubertal children: ethnic and geographic comparisons between New York City and Jinan City (China). *J Appl Physiol (1985)* 2009; **107**: 488–493.
12 Sarmiento OL, Parra DC, Gonzalez SA, Gonzalez-Casanova I, Forero AY, Garcia J. The dual burden of malnutrition in Colombia. *Am J Clin Nutr* 2014; **100**: 1628S–1635S.
13 Barreira TV, Staiano AE, Katzmarzyk PT. Validity assessment of a portable bioimpedance scale to estimate body fat percentage in white and African-American children and adolescents. *Pediatr Obes* 2013; **8**: e29–e32.