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1 **Short Communication**

2 **Association Between Body Mass Index and Body Fat in 9-11 Year Old Children from**
3 **Countries Spanning a Range of Human Development**

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30 **Running Title:** Pediatric BMI and Body Fat

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36 **Abstract**

37 The purpose was to assess associations between BMI and body fat in a multi-national sample
38 of 9-11 year old children. The sample included 7265 children from countries ranging in human
39 development. Total body fat (TBF) and percentage body fat (PBF) were measured with a Tanita
40 SC-240 scale and BMI z-scores (BMIz) and percentiles were computed using reference data
41 from the World Health Organization and the Centers for Disease Control and Prevention,
42 respectively. Mean PBF at BMIz values of -1, 0 and +1 were estimated using multi-level models.
43 Correlations between BMI and TBF were >0.90 in all countries, and correlations between BMI
44 and PBF ranged from 0.76 to 0.96. Boys from India had higher PBF than boys from several
45 other countries at all levels of BMIz. Kenyan girls had lower levels of PBF than girls from several
46 other countries at all levels of BMIz. Boys and girls from Colombia had higher values of PBF at
47 BMIz = -1, while Colombian boys at BMIz 0 and +1 also had higher values of PBF than boys in
48 other countries. Our results show a consistently high correlation between BMI and adiposity in
49 children from countries representing a wide range of human development.

50 **Keywords:** pediatric; overweight; global

51
52 **Trial Registration:** ClinicalTrials.gov: Identifier NCT01722500

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

66 Methods

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

74 Body mass and percentage body fat (PBF; %) were measured with a Tanita SC-240 scale
75 (Arlington Heights, IL, USA) after all outer clothing, heavy pocket items and shoes were
76 removed. Total body fat (TBF; kg) was computed by multiplying the body fat percentage by
77 body mass. Body height (cm) was measured without shoes using a Seca 213 portable
78 stadiometer (Hamburg, Germany), with the head in the Frankfort plane. Each measurement was
79 repeated and the average was used for analysis (a third measurement was obtained if the first
80 two measurements were greater than 0.5 cm apart for body height, 0.5 kg apart for body mass,

81 and 2.0% for PBF, respectively, and the average of the two closest measurements was used in
82 analyses). BMI was calculated [weight (kg)/ height (m²)] and age- and sex-specific z-scores
83 (BMIz) were computed using reference data from the World Health Organization (WHO).⁹
84 Further, age- and sex-specific BMI percentiles (%iles) were computed using reference data from
85 the US Centers for Disease Control and Prevention (CDC).¹⁰

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

93 Results

94 The mean (SD) values for age and BMI were 10.4 (0.6) y and 18.5 (3.5) kg/m², respectively
95 and the mean CDC BMI %ile was 57.3 (30.3) and WHO BMIz was 0.48 (1.26). The
96 corresponding means for PBF and TBF were 21.0 (7.7) % and 8.4 (5.4) kg, respectively. Table
97 1 presents correlations among the BMI variables and TBF and PBF across all ISCOLE research
98 sites. The correlations between BMI and TBF were consistently above 0.90 in all 12 countries,
99 and the correlations between BMI and PBF were between 0.76 and 0.96. Thus, BMI and
100 bioelectrical impedance-derived estimates of body fat were highly correlated across all ISCOLE
101 sites.

102 Figure 1 presents the mean levels of PBF in boys and girls at WHO BMIz of -1, 0 and +1.
103 The interaction between WHOz and site in the multi-level model was significant (p<0.001) in
104 both boys and girls. It is clear that absolute level of PBF increases across levels of WHO BMIz
105 in both boys and girls. Across all countries combined: BMIz = -1 corresponds to a PBF of 10.5%
106 in boys and 15.0% in girls; BMI = 0 corresponds to a PBF of 15.9% in boys and 20.4% in girls;

107 and BMI = +1 corresponds to PBF of 21.2% in boys and 25.7% in girls. As indicated in the figure
108 legend, there were several significant differences in PBF at a given level of WHO BMIz across
109 sites. In particular, boys from India had significantly higher PBF than boys from several other
110 countries at all levels of WHO BMIz. Further, Kenyan girls had significantly lower levels of PBF
111 than girls from several other countries at all levels of BMI, especially at WHO BMIz values of 0
112 and +1. Both boys and girls from Colombia had higher values of PBF at WHO BMIz = -1 than
113 those in some other countries, while Colombian boys at WHO BMIz 0 and +1 also had higher
114 values of PBF than boys in some other countries. In boys, the largest mean differences between
115 countries were 4.7% between India and Portugal at BMIz = -1, 3.9% between India and
116 Portugal at BMIz = 0, and 3.4% at BMIz = +1 between India and Kenya. In girls, the largest
117 mean differences between countries were 3.7% between India and Kenya at BMIz = -1, 4.1%
118 between India and Kenya at BMIz = 0, and 4.4% at BMIz = +1 between India and Kenya.
119 Overall, 92% of the comparisons between countries were within 3% PBF and 81% were within
120 2% PBF.

121 Discussion

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

128 These results support previous studies that have documented strong associations between
129 BMI and adiposity in children. For example, Pietrobelli et al.³ reported R² values of 0.85 and
130 0.89 for the association between BMI and TBF measured by dual-energy x-ray absorptiometry
131 (DXA) in a sample of 5-19 year old Italian boys and girls, respectively. An analysis of data from
132 6-11 year old children from the U.S. National Health and Nutrition Examination Survey

133 (NHANES) reported correlations of 0.81 and 0.88 between BMI-for-age and PBF and
134 correlations of 0.77 and 0.82 between BMI-for age and TBF in boys and girls, respectively.⁴
135 These results are similar to ours, where the overall (total sample) correlation is 0.81 between
136 CDC BMI %ile and PBF and 0.76 between CDC BMI %ile and TBF. Similarly, the Pearson
137 correlations of BMI with PBF and TBF were 0.83 and 0.93, respectively, in a sample of 3-12
138 year old children from New York City (white, African American, Chinese and Korean) and
139 China¹¹. In that study, for a given level of BMI, Asians (from China and Korea) had higher levels
140 of PBF than white and African Americans. In our study, we found that boys and girls from India
141 had significantly higher PBF than boys in several other countries, but Chinese boys and girls did
142 not stand out as being different than children from other counties. The results for Colombia may
143 partially be a reflection of altered relationships between BMI and body composition associated
144 with the double burden of malnutrition.¹²

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

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

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171 families who made this study possible. A membership list of the ISCOLE Research Group and
172 External Advisory Board is included in Katzmarzyk, Lambert and Church. An Introduction to the
173 International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE). Int J Obes
174 Suppl. (This Issue).

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176 collection and analysis, decision to publish, or preparation of the manuscript.

177

178 **Conflicts of Interest**

179 MF has received a research grant from Fazer Finland and has received an honorarium for
180 speaking for Merck. AK has been a member of the Advisory Boards of Dupont and McCain
181 Foods. RK has received a research grant from Abbott Nutrition Research and Development. VM
182 is a member of the Scientific Advisory Board of Actigraph and has received an honorarium for
183 speaking for The Coca-Cola Company. TO has received an honorarium for speaking for The
184 Coca-Cola Company. The authors reported no other potential conflicts of interest.

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223

224 **Figure Legend**

225

226 **Figure 1.** Levels of percentage body fat (PBF) at WHO BMIz values of -1, 0 and 1 in 7265 A)
227 boys and B) girls from the International Study of Childhood Obesity, Lifestyle and the
228 Environment (ISCOLE). Error bars represent standard errors. WHO BMIz computed from
229 reference data from the World Health Organization.⁹ Significant differences in boys: at WHO
230 BMIz = -1: Colombia > Canada, China, Portugal; India > Canada, China, Finland, Kenya,
231 Portugal, South Africa, United Kingdom & United States; Portugal < Colombia, Kenya, India &
232 South Africa; at WHO BMIz = 0: Colombia > China, Finland & Portugal; India > Australia, Brazil,
233 Canada, China, Colombia, Finland, Kenya, Portugal, United Kingdom & United States; Portugal
234 < South Africa, Colombia & India; at WHO BMIz = +1: Colombia > Kenya; India > Australia,
235 Brazil, Canada, China, Colombia, Finland, Kenya, Portugal, United Kingdom; US > China,
236 Finland, Portugal & Kenya; Brazil > Kenya. Significant differences in girls: at WHO BMIz = -1:
237 Kenya < Canada, Colombia, India, South Africa, United Kingdom & United States; Colombia >
238 Brazil, China, Finland, Kenya, & Portugal; Finland < Colombia, India, South Africa & United
239 Kingdom, India > China & Finland; South Africa > Kenya, Finland & Portugal; at WHO BMIz = 0:
240 Kenya < Australia, Brazil, Canada, Colombia, Finland, India, Portugal, South Africa & United
241 States; at WHO BMIz = +1: Kenya < Australia, Brazil, Canada, Colombia, Finland, India,
242 Portugal, South Africa, United Kingdom & United States.

243

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

| | Australia | Brazil | Canada | China | Colombia | Finland | India | Kenya | Portugal | South Africa | United Kingdom | United States |
|--------------------|-----------|--------|--------|-------|----------|---------|-------|-------|----------|--------------|----------------|---------------|
| <i>Boys</i> | | | | | | | | | | | | |
| 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 |
| <i>Girls</i> | | | | | | | | | | | | |
| 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 |

TBF: total body fat; PBF: percentage body fat.

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 standard errors. 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, United Kingdom & United States; Portugal < Colombia, Kenya, India & South Africa; at WHO BMIz = 0: Colombia > China, Finland & Portugal; India > Australia, Brazil, Canada, China, Colombia, Finland, Kenya, Portugal, United Kingdom & United States; Portugal < South Africa, Colombia & India; at WHO BMIz = +1: Colombia > Kenya; India > Australia, Brazil, Canada, China, Colombia, Finland, Kenya, Portugal, United Kingdom; US > China, Finland, Portugal & Kenya; Brazil > Kenya. Significant differences in girls: at WHO BMIz = -1: Kenya < Canada, Colombia, India, South Africa, United Kingdom & United States; Colombia > Brazil, China, Finland, Kenya, & Portugal; Finland < Colombia, India, South Africa & United Kingdom, India > China & Finland; South Africa > Kenya, Finland & Portugal; at WHO BMIz = 0: Kenya < Australia, Brazil, Canada, Colombia, Finland, India, Portugal, South Africa & United States; at WHO BMIz = +1: Kenya < Australia, Brazil, Canada, Colombia, Finland, India, Portugal, South Africa, United Kingdom & United States.

