Body mass index adjustments to increase the validity of body fatness assessment in UK black African and South Asian children

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ABSTRACT

Background/Objectives: BMI (weight/height^2) is the most widely used marker of childhood obesity and total body fatness (BF). However, its validity is limited, especially in children of South Asian and black African origins. We aimed to quantify BMI adjustments needed for UK children of black African and South Asian origins so that adjusted BMI related to BF in the same way as for white European children.

Methods: We used data from four recent UK studies which made deuterium dilution BF measurements in UK children of white European, South Asian and black African origins. A height-standardized fat mass index (FMI) was derived to represent BF. Linear regression models were then fitted, separately for boys and girls, to quantify ethnic differences in BMI-FMI relationships and to provide ethnic-specific BMI adjustments.

Results: We restricted analyses to 4-12 year-olds, to whom a single consistent FMI (fat mass/height^5) could be applied. BMI consistently underestimated BF in South Asians, requiring positive BMI adjustments of +1.12kg/m^2 (95% CI: 0.83, 1.41 kg/m^2; P<0.0001) for boys and +1.07kg/m^2 (95% CI: 0.74, 1.39 kg/m^2; P<0.0001) for girls of all age groups and FMI levels. BMI overestimated BF in black Africans, requiring negative BMI adjustments for black African children. However, these were complex because there were statistically significant interactions between black African ethnicity and FMI (P=0.004 boys; P=0.003 girls) and also between FMI and age group (P<0.0001 for boys and girls). BMI adjustments therefore varied by age group and FMI level (and indirectly BMI); the largest adjustments were in younger children with higher unadjusted BMI and the smallest in older children with lower unadjusted BMI.

Conclusion: BMI underestimated BF in South Asians and overestimated BF in black Africans. Ethnic-specific adjustments, increasing BMI in South Asians and reducing BMI in black Africans, can improve the accuracy of BF assessment in these children.

INTRODUCTION

Overweight and obesity in UK children represent a major public health challenge (1), with both short and long-term consequences for physical and mental health (2-5). Accurate assessment of total BF is critical for effective surveillance, prevention, diagnosis and management of this problem (6). Body mass index (BMI) (weight/height^2) is the most widely used marker of obesity and total BF in children as well as adults, providing the basis for most widely used definitions of childhood overweight and obesity (7, 8). However, the validity of BMI as a marker of childhood total BF is limited (9), particularly in UK South Asian and black African ethnic minority populations. BMI systematically underestimates total BF in UK South Asian children (10, 11) and systematically overestimates total BF in UK black African children (10, 11). These errors are a cause for concern in both ethnic groups but especially in UK South Asian children, who have a higher burden of total BF and obesity (10, 11), greater metabolic sensitivity to the effects of BF (12, 13) and high long-term risks of complications of increased BF, particularly type 2 diabetes and cardiovascular disease (14, 15).

The errors in the measurement of BMI could potentially be addressed by adjusting BMI for ethnicity (16), so that adjusted BMI values have the same relationship to total BF as in white Europeans (11). We have therefore pooled data from four studies which used the deuterium dilution method to make accurate measurements of body water - and indirectly of fat free mass (FFM) and fat mass (FM) - in UK boys and girls of white European, South Asian and black African origins aged 4-15 years. These data were used to quantify the BMI adjustments needed for South Asian and black African children, to ensure that adjusted BMI values had the same relationship to total BF (expressed as a fat mass index [FMI]) as in white Europeans (11).

METHODS

Data Sources

Data from four recent studies which used the deuterium dilution method to measure total body water (TBW) (and indirectly FM) in population-based samples of UK children aged between 4 and 15 years, were obtained and pooled for analysis. Details of these studies and their participants are provided in Supplementary Tables S1 and S2. Three of the four studies were carried out during the last 10 years and were primarily population-based studies based in primary or secondary schools, including approximately equal numbers of children of white European, South Asian and black African origin (11, 17, 18); a small number of individuals in the ELBI study (17) who were recruited from an obesity clinic (n = 19) were excluded from analysis. The fourth study, conducted over several years, predominantly included white European volunteers recruited by advertisement (19). Ethnicity was based on a combination of self-reported parental information on parental ethnicity (11), child ethnicity (11, 18, 19), with self-reported participant information on ethnicity for older children (17, 19), using ethnic group categories based on the 2001 UK Census. For the present analyses, child ethnicity was categorized as white European, black African (including both African and Caribbean descent), South-Asian (including Indian, Pakistani, Bangladeshi and Sri Lankan descent), other ethnic group (including mixed ethnicity) and unknown ethnic group.

In all four studies, participants had standardized measurements of height and weight and TBW measured using the deuterium dilution method. They received standard deuterium oxide dosages and saliva samples were obtained for deuterium measurement at baseline and between 4 and 5 hours post-dose; participants avoided food and drink for at least 30 minutes before each sample. All fluid consumption between the deuterium dose and the second saliva sample was documented. Deuterium concentrations in each saliva sample and each individual deuterium dose were measured by isotope-ratio mass spectrometry (19). TBW was calculated

incorporating a correction for the exchange of deuterium with non-aqueous hydrogen (20) and adjusting for fluid intake during the equilibrium period. FFM was calculated from TBW using assumed hydration of lean tissue (21); FM was calculated as the difference between body weight and FFM.

Statistical Methods

Standardising Fat Mass for height

To investigate the relationship between BMI and total BF, it was first necessary to derive a height-independent FMI. To accurately assess the height power needed, log transformed FM (dependent variable) was regressed on log transformed height (independent variable) (22), adjusting for sex and age in one year age groups. We then investigated whether the height power varied by age, ethnicity or sex by fitting two-way interaction terms between log height and these covariates. An interaction term for log height with age (in one year intervals) was included first and its statistical significance was assessed by means of a likelihood ratio test, followed by fitting of an interaction term for log height with ethnicity (interactions for South Asians and black Africans were evaluated separately) and finally for log height with sex. Statistical significance was set at the 5% significance level for all likelihood ratio tests. In sensitivity analyses, models were stratified by sex and the above model building procedure was repeated.

Regression models relating body mass index and fat mass index

Regression models, stratified by sex, were used to quantify the ethnic differences in BMI-FMI relationships. BMI was regressed against FMI with additional covariates for ethnic group and age. Age was fitted in three pre-specified 3-year groups (4.0 – 6.9 years, 7.0 – 9.9

years and 10.0 – 12.9 years) to provide robust and stable age-specific estimates by sex, ensuring that all potentially pubertal children would be in the third group. Examination of the data suggested that the use of these 3 year age groups accounted for age effects adequately without a need for finer age divisions. All two-way interaction terms between FMI, ethnicity and age groups were included in the model using a stepwise forwards approach (23) and three way interactions were only considered if their corresponding two-way interactions were statistically significant. The statistical significance of each interaction term was tested using the likelihood ratio test at the 5% significance level. All statistically significant interactions were included in the model, and model fit was checked by assessing residual plots and measures of R^2 gave an indication of the amount of variation explained by the model. These regression models were used to construct plots of BMI against FMI in each ethnic group by the three year age categories for boys and girls, to demonstrate ethnic differences in the BMI-FMI relationships. Finally, the ethnicity adjustments for each age and sex group were derived from the best fitting regression model coefficients (as explained in detail in Appendix 1). A summary of adjusted BMI values for unadjusted BMI values between 13 and 25 kg/m^2 (5th to 95th BMI centiles for the 4-12 year-old study population) is presented (Table 1), together with full tabulations of adjusted BMI values and of adjustment factors for each 0.1 kg/m^2 BMI increment across the complete BMI range in this study population (12-36.9 kg/m^2) (Supplementary Tables S3 and S4 respectively).

RESULTS

Table 2 shows mean (SD) height, weight, BMI, FM and FFM values for boys and girls within each age group from the combined dataset. Mean levels of all variables increased with age group, for both boys and girls. Across age groups, girls had a greater average weight and FM than boys. Black African children were consistently taller, weighed more and had a higher FFM than other ethnic groups, except in the oldest girls. Slightly different patterns were

observed for FM; black African and South Asian children had higher FM than white Europeans of the same age group with the exception of girls in the oldest age group. Histograms showing the distributions of BMI, weight, FM and FFM by sex and age groups are presented in Supplementary Figure S1.

Standardising Fat Mass for height

Based on a model regressing log FM on log height, age groups, sex and ethnicity, the age-specific height powers providing a height-independent FMI for both sexes combined are presented in Figure 1. From the model, the optimal height power was consistently close to 5 between 4 and 12 years, but declined markedly from 13 years upwards; the interaction between log height and one year age groups was highly statistically significant ($P_{lrtest} < 0.0001$). In children aged 4-12 years (with older children excluded), there was no evidence of interaction between log height and one year age groups ($P_{lrtest} = 0.87$), suggesting that the height power was consistent across this slightly restricted age range. There was evidence of interaction between log height and black African ethnicity ($P_{lrtest} = 0.01$) but no evidence of an interaction between log height and South Asian ethnicity ($P_{lrtest} = 0.72$); the estimated optimal height powers were 5.6 in black Africans, 4.9 in white Europeans and 4.8 in South Asians. As it was crucial to have a constant height power across ethnic groups so that FMI was on the same scale, we investigated the use of these different height powers in the derivation of FMI. The absolute magnitude of the difference in FMI obtained using height powers between 5.6 or 4.8 was very small and the correlation between the FMI with height powers of 5.6 and 4.8 was very high (r=0.99) and (by definition) the ranking of individuals remained the same across the range of FMI. We therefore excluded the black African interaction with log height from the model. There was no evidence of interaction between log height and sex ($P_{lrtest} = 0.26$). The overall height power needed to standardise FM for children aged 4 – 12 years was 5.05; for simplicity a power of 5.00 was used to derive FMI (kg/m^5)

for all children. Sensitivity analyses stratified by sex showed that the height powers needed for boys and girls were similar (Supplementary Figures S2 & S3), but model coefficients were less stable in sex-specific analyses.

Regression models relating body mass index and fat mass index

The forward stepwise procedure regressing BMI on FMI, ethnicity and age groups separately for each sex elicited the same order of selection of covariates in boys and girls. In addition to main effects (ethnicity and age groups), the strongest two-way interaction was between FMI and age group ($P_{lrtest}<0.0001$ in boys and girls) followed by FMI and black African ethnicity ($P_{lrtest} = 0.004$ in boys and $P_{lrtest} = 0.003$ in girls). Other two-way interactions were not statistically significant at the 5% level (Supplementary Table S3).

Graphical summaries of these modelled associations are presented in Figure 2 for boys and girls. The associations between BMI and FMI differed between ethnic groups. As the child's age increased, the BMI-FMI relationships became steeper for all ethnic groups. Both South Asian boys and girls had a consistently lower BMI for any given FMI than their white European counterparts for all three age groups; the BMI differences were constant at different FMIs and different age groups. Black African children, compared to white Europeans, had a higher BMI for any given FMI. However, the differences between the black Africans and white Europeans increased further at higher levels of FMI. (For example, the absolute differences in BMI between black African and white European children for a given FMI of $2kg/m^5$, $4kg/m^5$ and $6kg/m^5$ were $1.3kg/m^2$, $2.2kg/m^2$ and $3.1kg/m^2$ respectively) The corresponding regression coefficients (from which the figures were produced) are presented in Table 3. Normal plots of the residual did not show any departures from normality and there was no evidence of residual curvature when residuals were plotted against fitted values. The

overall R^2 values indicated that the final models explained 74% of the variance in BMI for boys and 72% for girls.

Ethnic-specific BMI adjustments

In order to ensure that BMI related to FMI in the same way for children from all ethnic groups, BMI adjustments were derived using the coefficients from the final models in Table 3. Unadjusted and adjusted BMI values for the BMI range 13 to 25 kg/m^2 are presented at 1.0 kg/m^2 intervals for South Asian and black African children (Table 1); unadjusted and adjusted BMI values and adjustment factors are presented for the full BMI range (12-37 kg/m^2) at more precise increments of 0.1 kg/m^2 for black African children (Supplementary Tables S3 and S4). For South Asian children, BMI adjustments were positive and constant across age groups and FMI levels, +1.12kg/m^2 (95% CI: 0.83kg/m^2, 1.41kg/m^2) for boys and +1.07kg (95% CI: 0.74kg/m^2, 1.39kg/m^2) for girls. In contrast, BMI adjustments for children of black African origin were negative and depended on age group and FMI level (and indirectly on unadjusted BMI level) because of the interactions between black African ethnicity and FMI and between FMI and age group. Adjustments were smaller in older age groups and increased with FMI levels, and thus with unadjusted BMI. Adjustments varied between -0.13 kg/m^2 (boys) and -0.12 kg/m^2 (girls) in 10-12 year-olds with low unadjusted BMI values and -5.52 kg/m^2 (boys) and -5.06 kg/m^2 (girls) in 4-6 year-olds with high unadjusted BMI values (Supplementary Table 4).

DISCUSSION

The aim of this research was to determine whether simple adjustments could be made to BMI values in South Asian and black African children in order to provide BMI values with similar relations to total BF as those in white European children. In South Asian children aged between 4 and 12 years, single adjustment factors for South Asian boys and girls, adding

237 approximately 1.1 kg/m^2 to the unadjusted BMI value irrespective of age and FMI, achieved
238 this aim. For black African children, negative adjustment factors achieved this aim, but these
239 varied strongly with age and with FMI (and indirectly with unadjusted BMI); the smallest
240 adjustment factors were applicable to older children with low BMI values and the largest to
241 younger children with high BMI values.

242 **Consistency with previous reports**

243 The optimal FMI in children aged 4-12 years (FM/height^5), was consistent with the results of
244 earlier studies in 8 year-old children (22) and 9-10 year-old children (10). In children aged 13
245 years and over, the optimal height power was markedly lower, reaching approximately 2 by
246 14 years of age. This is broadly consistent with a previous report suggesting an optimal
247 height power of 2 for FMI in young adults (24). The low BMI levels in relation to FMI in
248 South Asian children are consistent with previous reports in children based on bioimpedance
249 (10), deuterium dilution (11, 25) and dual-energy X-ray absorptiometry (DXA) (26) and with
250 earlier studies in Asian adult populations (27). The high levels of BMI in relation to FMI in
251 black Africans are consistent with previous reports based on bioimpedance (10), deuterium
252 dilution (11), DXA (26) and skinfold thickness measurements (28). As previously noted (10),
253 these distinct ethnic patterns probably have different explanations, with the pattern in South
254 Asian children reflecting the systematically higher FM and lower lean mass at a given BMI in
255 children of approximately similar height (10, 27). In contrast, the pattern in black African
256 children is likely to reflect their markedly greater height and different body shape. The
257 positive BMI adjustments described here for South Asian children are consistent in direction
258 with the lower BMI thresholds recommended for the definition of obesity in UK South Asian
259 adults based on equivalent type 2 diabetes risk (29, 30). However, the size of the adjustments
260 described here for South Asian children are markedly smaller than the adjustments in adult

BMI thresholds, probably reflecting both the younger age group in the present study and different point of reference (total BF levels rather than T2D risk levels).

Strengths and Limitations

To our knowledge, this is the first analysis to use the deuterium dilution reference method to quantify BMI-FMI relationships in UK South Asian and black African children across a relatively wide age range, in order to provide ethnic-specific BMI adjustments. BMI is a widely used marker of obesity and total BF in white European children (31); the deuterium dilution method provides accurate, safe and minimally invasive measurements of TBW (and FM) with an error of <1% (32, 33). The investigation was based on a pooled data resource including large numbers of UK children of South Asian and black African origin as well as reference populations of white European children, allowing reasonably precise quantification of ethnic differences in the BMI-FMI relationship in the three main ethnic groups across a wide age range across which a single FMI could be applied (4-12 years), which importantly included both the younger (4-5 years) and older (10-11 years) age groups of the English National Child Measurement Programme, groups in which the need for accurate BMI interpretation is particularly pressing. However, this approach could not be applied to older children (13-15 years) who had a very different optimal FMI from that in 4-12 year-olds. Although the study had limited ability to define separate adjustments for Indians, Pakistanis and Bangladeshis and for black Africans of African and Caribbean descent, exploration of data for these separate ethnic subgroups suggested that there was no appreciable heterogeneity in BMI-FMI associations within the main South Asian and black African groups, so that the adjustments provided should be widely applicable to UK South Asian and black African children, who together account for a substantial proportion of the UK ethnic minority child population. However, the combined study resource included few children of other specific ethnic groups and children of mixed ethnicity; separate and specific studies

would be needed to examine whether adjustments are needed in these other population groups. The generalizability of the adjustments developed for South Asian and black African children outside the UK setting remains uncertain. It is possible that they are valid for children of South Asian and African origins in other Western countries, though this would require independent confirmation. We would however advise caution in the use of these adjustments in countries with majority South Asian or black African populations, particularly when country-specific reference data are being used to define weight status.

The use of equivalent total body fatness as a reference point for deriving BMI adjustments in children is supported by its strong relationship to insulin resistance in childhood (12) and by its greater contribution to explaining the higher levels of emerging insulin resistance and T2D risk in childhood than simple markers of central and visceral adiposity (12, 34). However, it is possible that using equivalent levels of visceral fat, which is particularly implicated in insulin resistance and type 2 diabetes risk in adults (35, 36), as the basis for adjustments would have advantages over total BF. There is some evidence that South Asian adults have a greater proportional excess of visceral fat than total BF (37), which would suggest that adjustments needed for South Asians could be larger than those indicated by equivalent total BF. However, this pattern has not been consistently reported in all studies (38) and accurate data on ethnic differences in visceral fat in UK children are currently limited. It is also possible that South Asian children in particular have greater metabolic sensitivity to the effects of body fatness (including total BF) than white Europeans (12). This would also raise the possibility that BMI adjustments for South Asian children should be larger than those based on equivalent total BF, though again currently available data do not allow this possibility to be addressed in the formulation of adjustments.

Implications: potential for application in practice

We have shown that it is possible to derive adjusted BMI values for UK South Asian and black African boys and girls, which are related to total BF (represented by FMI) in the same way as in white European children. For South Asians, the adjustments are positive and very simple, with increases of ~1.1 kg/m^2 both for boys and girls, irrespective of age and FMI. For black Africans, the adjustments needed are negative and dependent on age group and FMI level, varying between -0.12 kg/m^2 and -5.52 kg/m^2. Such adjustments should overcome the underestimation of total BF in South Asian children and its overestimation in black African children which arise when unadjusted BMI is used (10, 12). These adjustments should be applicable for all UK children of South Asian and black African origin; they may also be applicable in other settings but further evaluation will be needed. Once the relevant ethnic-specific adjustments are applied, it should then be possible to estimate weight status using the standard definitions used in the UK, including the UK90 and IOTF classification systems (8, 39). The use of this approach is therefore effectively using ethnic-specific assessment of BMI and it therefore departs from earlier recommendations which have expressed caution or opposed ethnic-specific assessment of BMI in UK children (40, 41), though such assessment is now advocated in adults (29, 41). However, this approach, with initial BMI adjustment followed by the use of standard definitions for weight status relevant to the local population would be a simple process to implement and would avoid the need for new ethnic-specific BMI cut-offs for categorizing weight status in individual children, thereby reducing the scope for error and confusion.

Application of these adjustments should reduce the misclassification of individual children between normal and overweight-obese categories. It would however result in an appreciable increase in the prevalences of overweight-obesity in South Asian children, with a reduction in overweight-obesity prevalences in black African children. For control of childhood overweight-obesity and its consequences, this reduction in the under diagnosis of overweight

and obesity in UK South Asian children would be particularly important; these children have higher levels of total BF than white Europeans (10, 12) and are at high long term risk of type 2 diabetes and cardiovascular diseases (13, 42). In addition, the application of these adjustments to population-based data on BMI in children, particularly in national surveys including the National Child Measurement Programme (43) and the Health Survey for England (14) should increase the accuracy with which population burdens of total BF, overweight and obesity in UK children from different ethnic groups are assessed.

The adjustments can be applied directly from the specific estimates provided above for South Asian children and for black African children using the age and BMI-specific data presented for each 0.1 kg/m^2 of BMI in Supplementary Table S3. Alternatively, a web-based calculator developed by the authors can be used, which links the calculation of adjusted BMI values (given the age, sex, weight, height and ethnicity of the individual child) to the weight status definitions (underweight, healthy, overweight, obese) provided by the UK90 reference populations.

Conclusion

The relationships between BMI and FMI differ between South Asians, black Africans and white Europeans in children aged 4-12 years, so that BMI underestimates BF in South Asians and overestimates it in black Africans. BMI adjustments have been calculated for UK South Asian and black African children, so that adjusted BMI values are related to FMI in the same way as in white Europeans. These can be used to make the assessment of BF more accurate, both in individual UK children of South Asian and black African origins and in the UK child population as a whole.

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Study design – MTH, CMN, PHW, CGO, ARR, DGC, JCKW

Data collection - PHW, CMN, CGO, ASD, SL, JEW, DH, MSF, JCKW, ARR, DGC

Data analysis – MTH, ARR, DGC, CMN

Data interpretation - MTH, PHW, ARR, CGO, DGC, JCKW

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Competing interests:

We declare that we have no conflicts of interest.

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Figure Legends

FIGURE 1: OPTIMAL HEIGHT POWERS FOR FAT MASS INDEX IN CHILDREN 4-15 YEARS BY AGE (YEARS) AND ETHNICITY

FIGURE 2: RELATIONSHIPS BETWEEN BMI AND FAT MASS INDEX BY AGE GROUP FOR CHILDREN OF WHITE EUROPEAN, BLACK AFRICAN AND SOUTH ASIAN ORIGIN

TABLE 1: UNADJUSTED AND ADJUSTED BODY MASS INDEX (BMI) VALUES FOR UK BLACK AFRICAN AND SOUTH ASIAN CHILDREN BY SEX AND AGE GROUP

TABLE 2: ANTHROPOMETRIC AND ADIPOSITY MEASURES IN CHILDREN 4-15 YEARS BY SEX, ETHNICITY AND 3-YEAR AGE GROUPS

TABLE 3: COEFFICIENTS FOR REGRESSION OF BODY MASS INDEX ON FAT MASS INDEX ADJUSTED FOR ETHNICITY AND AGE GROUP: BY SEX

Black Africans

BMI (kg/m^2)	Boys Adjusted BMI (kg/m^2)			Girls Adjusted BMI (kg/m^2)		
	4-6 years	7-9 years	10-12 years	4-6 years	7-9 years	10-12 years
13.0	12.57	12.54	12.75	12.51	12.51	12.77
14.0	13.36	13.40	13.63	13.32	13.38	13.66
15.0	14.14	14.27	14.51	14.13	14.26	14.55
16.0	14.93	15.13	15.39	14.94	15.14	15.44
17.0	15.72	15.99	16.26	15.75	16.01	16.33
18.0	16.50	16.85	17.14	16.56	16.89	17.22
19.0	17.29	17.72	18.02	17.37	17.77	18.11
20.0	18.08	18.58	18.90	18.17	18.64	19.00
21.0	18.87	19.44	19.78	18.98	19.52	19.88
22.0	19.65	20.30	20.66	19.79	20.40	20.77
23.0	20.44	21.17	21.54	20.60	21.28	21.66
24.0	21.23	22.03	22.42	21.41	22.15	22.55
25.0	22.02	22.89	23.29	22.22	23.03	23.44

South Asians

BMI (kg/m^2)	Boys Adjusted BMI (kg/m^2)			Girls Adjusted BMI (kg/m^2)		
	4-6 years	7-9 years	10-12 years	4-6 years	7-9 years	10-12 years
13.0	14.12	14.12	14.12	14.07	14.07	14.07
14.0	15.12	15.12	15.12	15.07	15.07	15.07
15.0	16.12	16.12	16.12	16.07	16.07	16.07
16.0	17.12	17.12	17.12	17.07	17.07	17.07
17.0	18.12	18.12	18.12	18.07	18.07	18.07
18.0	19.12	19.12	19.12	19.07	19.07	19.07
19.0	20.12	20.12	20.12	20.07	20.07	20.07
20.0	21.12	21.12	21.12	21.07	21.07	21.07
21.0	22.12	22.12	22.12	22.07	22.07	22.07
22.0	23.12	23.12	23.12	23.07	23.07	23.07
23.0	24.12	24.12	24.12	24.07	24.07	24.07
24.0	25.12	25.12	25.12	25.07	25.07	25.07
25.0	26.12	26.12	26.12	26.07	26.07	26.07

Adjusted BMI values based on coefficients from best fitting regression models in Table 2 for one kg/m2 intervals between 13 and 25 kg/m2 (5th to 95th BMI centiles) .
For precise unadjusted and corresponding adjusted BMI at 0.1 kg/m2 increments across the full BMI range see Supplementary Table 5.

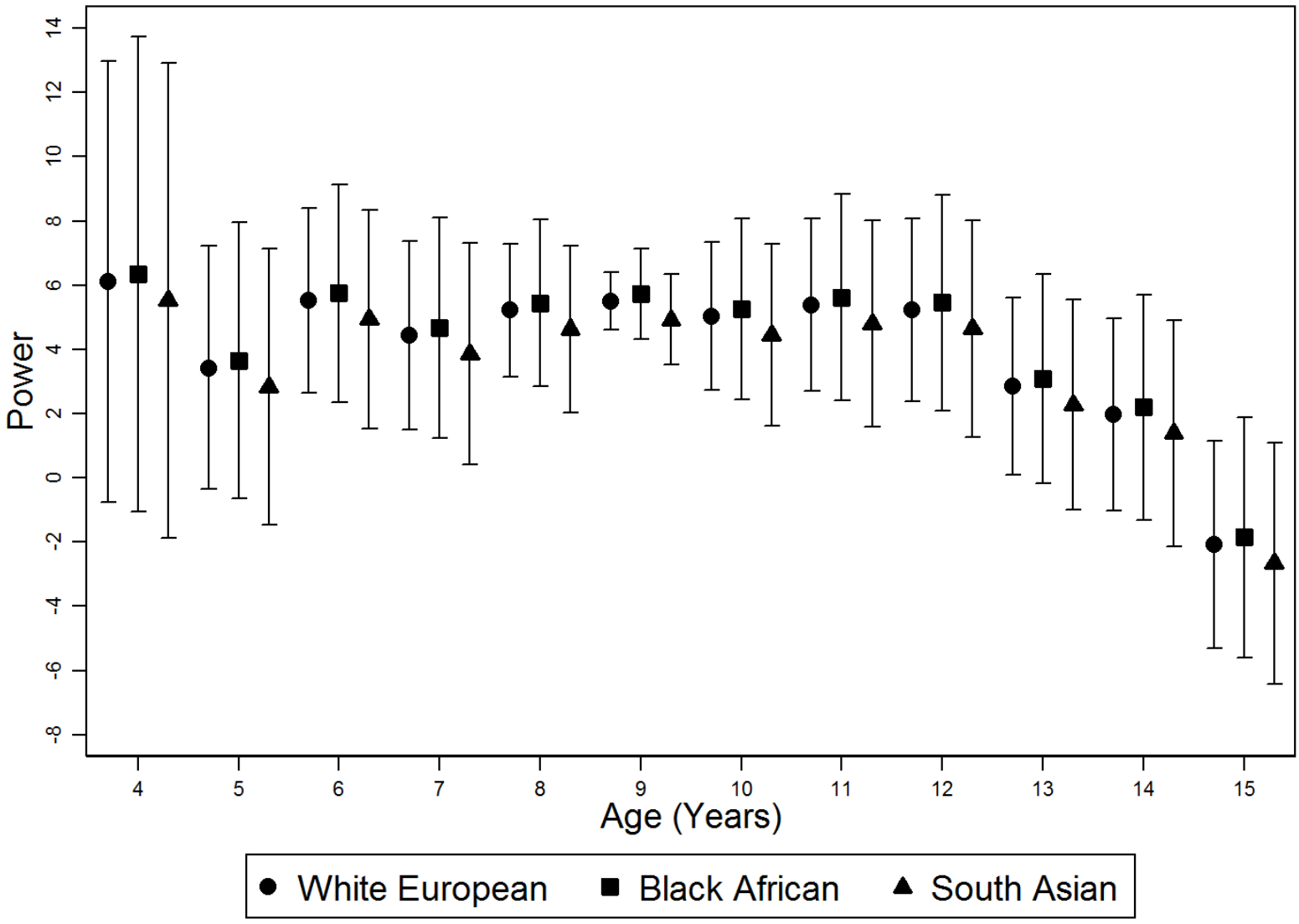
	BOYS			GIRLS		
	White European	Black African	South Asian	White European	Black African	South Asian
4 - 6 years						
N	38	21	19	44	23	17
Height (cm)	115.8 (7.2)	122.2 (7.8)	116.8 (6.3)	116.4 (6.2)	120.9 (6.1)	117.2 (6.0)
Weight (kg)	21.9 (4.5)	25.8 (6.6)	21.1 (4.6)	22.2 (4.2)	24.4 (4.4)	22.7 (5.6)
Body Mass Index (kg/m²)	16.2 (1.8)	17.1 (2.8)	15.4 (2.4)	16.2 (2.1)	16.6 (2.3)	16.4 (2.9)
Fat mass (kg)	4.4 (2.2)	5.6 (3.5)	5.0 (2.8)	5.5 (2.5)	5.9 (2.3)	6.6 (3.5)
Fat Free Mass (kg)	17.4 (2.8)	20.2 (3.6)	16.1 (2.3)	16.7 (2.4)	18.5 (2.7)	16.1 (2.4)
7 - 9 years						
N	205	146	179	209	173	170
Height (cm)	134.1 (7.0)	137.8 (7.6)	134.2 (7.2)	132.9 (6.8)	137.9 (7.4)	133.6 (7.5)
Weight (kg)	30.4 (6.4)	35.6 (9.0)	31.8 (7.9)	31.3 (7.2)	36.9 (10.9)	31.4 (8.7)
Body Mass Index (kg/m²)	16.8 (2.5)	18.5 (3.1)	17.5 (3.2)	17.6 (2.9)	19.2 (4.4)	17.4 (3.5)
Fat mass (kg)	7.2 (4.0)	9.3 (5.4)	10.0 (5.1)	9.0 (4.4)	11.6 (6.7)	10.6 (5.2)
Fat Free Mass (kg)	23.3 (3.2)	26.3 (4.5)	21.8 (3.5)	22.3 (3.5)	25.3 (5.2)	20.8 (4.0)
10 - 12 years						
N	126	44	52	120	56	83
Height (cm)	146.9 (8.1)	149.8 (10.4)	145.2 (8.5)	147.5 (9.1)	151.6 (8.1)	145.6 (8.2)
Weight (kg)	39.8 (9.6)	48.5 (15.1)	39.2 (10.8)	42.5 (11.3)	49.1 (14.3)	40.0 (9.5)
Body Mass Index (kg/m²)	18.3 (3.2)	21.3 (5.1)	18.4 (4.0)	19.3 (3.6)	21.1 (5.0)	18.7 (3.3)
Fat mass (kg)	9.3 (5.8)	14.7 (9.4)	11.0 (6.7)	12.3 (6.6)	15.2 (8.3)	12.5 (5.5)
Fat Free Mass (kg)	30.4 (5.6)	33.9 (7.8)	28.2 (6.0)	30.2 (6.4)	33.9 (7.5)	27.4 (5.4)
13 - 15 years						
N	62	29	31	81	36	35
Height (cm)	164.5 (10.4)	169.5 (9.0)	163.7 (8.9)	161.1 (6.8)	160.5 (6.8)	154.1 (6.2)
Weight (kg)	53.4 (11.4)	62.9 (16.6)	54.3 (16.7)	56.9 (12.7)	54.4 (10.8)	44.5 (10.5)
Body Mass Index (kg/m²)	19.6 (2.9)	21.7 (4.6)	20.1 (5.2)	21.8 (4.5)	21.1 (3.7)	18.7 (4.4)
Fat mass (kg)	9.7 (6.0)	12.5 (9.5)	12.5 (10.7)	16.7 (7.7)	14.6 (7.7)	12.8 (6.8)
Fat Free Mass (kg)	43.7 (9.8)	50.4 (10.4)	41.8 (8.4)	40.1 (6.4)	39.9 (6.3)	31.7 (4.5)

		BOYS				GIRLS		
Variable		**Coefficient**	**95% CI**	**P-value**		**Coefficient**	**95% CI**	**P-value**
FMI (kg/m^5)		2.94	2.75 , 3.13	<0.001		3.04	2.83 , 3.26	<0.001
Black African		0.37	-0.25 , 0.99	0.242		0.29	-0.41 , 1.00	0.413
South Asian		-1.12	-1.41 , -0.83	<0.001		-1.07	-1.39 , -0.74	<0.001
Age group (years)	4 - 6	0.24	-0.82 , 1.29	0.661		0.63	-0.61 , 1.87	0.319
	7 - 9	[REFERENCE]				[REFERENCE]		
	10 - 12	1.64	1.08 , 2.19	<0.001		2.26	1.52 , 3.01	<0.001
Black African * FMI (kg/m^5)		0.46	0.15 , 0.77	0.004		0.44	0.14 , 0.73	0.004
FMI (kg/m^5) * Age group	4 - 6	-1.12	-1.59 , -0.65	<0.001		-1.26	-1.72 , -0.80	<0.001
	7 - 9	[REFERENCE]				[REFERENCE]		
	10 - 12	0.42	0.12 , 0.72	0.006		0.37	0.03 , 0.72	0.035
Constant		12.11	11.73 , 12.49	<0.001		11.08	10.56 , 11.60	<0.001

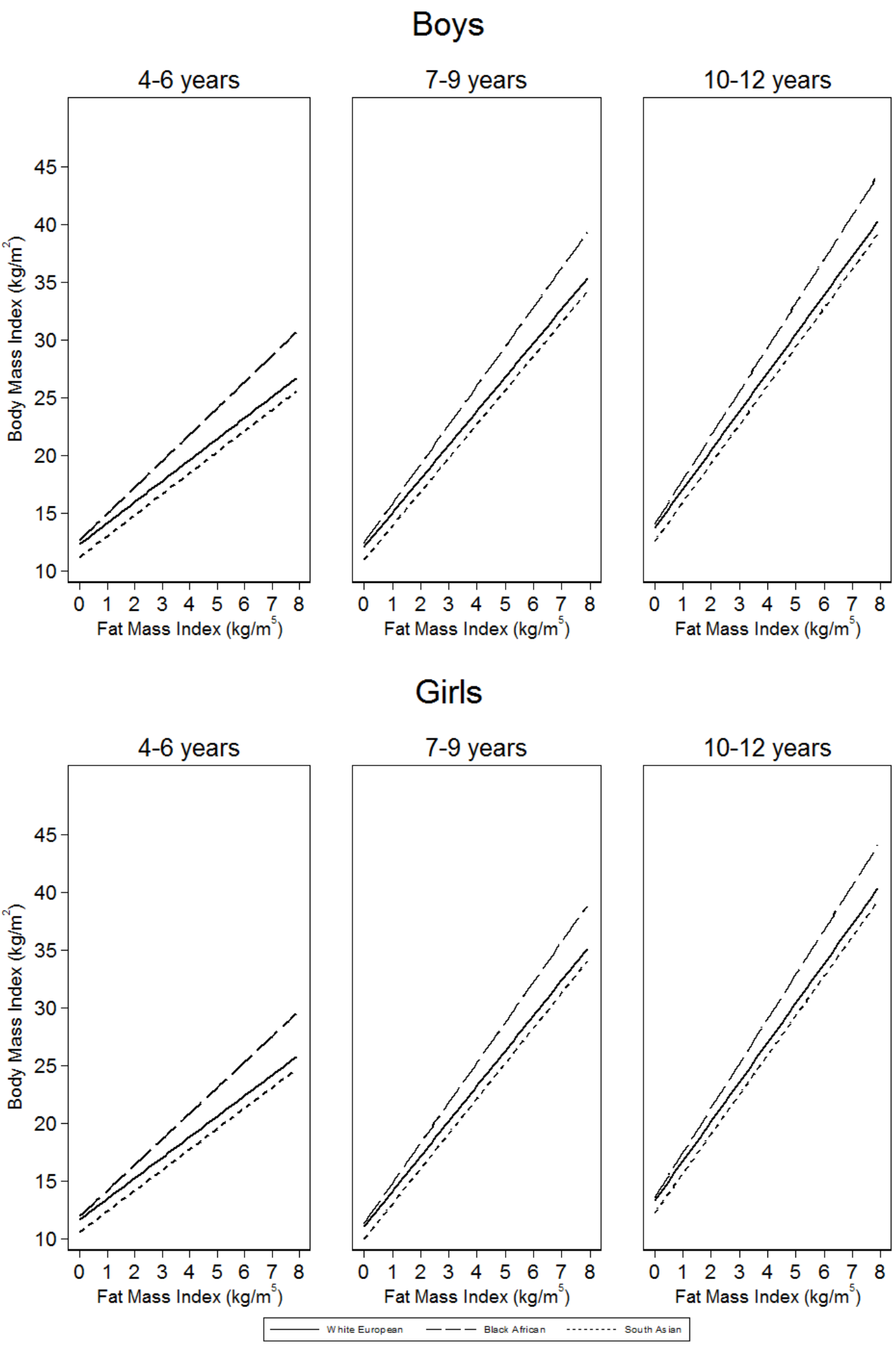
$R^2_{boys,\ girls}$ = 74.2%, 71.7%

Best fitting linear regression models fitted for boys and girls separately with adjustment for ethnicity and age group and including statistically significant interaction terms (denoted by an asterix)

P values based on likelihood ratio tests



Estimates are from regression analyses, including boys and girls, fitting log fat mass on log height with adjustment for age, ethnicity and sex and including interaction terms for age*log(height) and ethnicity*log(height).



Body Mass Index based on best fitting linear regression models presented in Table 2