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DEVELOPMENTAL ORIGINS OF HEALTH AND DISEASE

Patterns of body size and adiposity among UK children of South Asian, black African–Caribbean and white European origin: Child Heart And health Study in England (CHASE Study)

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Background The objective of this study was to examine adiposity patterns in UK South Asian, black African–Caribbean and white European children using a range of adiposity markers. A cross-sectional survey in London, Birmingham and Leicester primary schools was conducted. Weight, height, waist circumference, skinfold thickness values (biceps, triceps, subscapular and suprailiac) were measured. Fat mass was derived from bioimpedance; optimally height-standardized indices were derived for all adiposity markers. Ethnic origin was based on parental self-report. Multilevel models were used to obtain adjusted means and ethnic differences adjusted for gender, age, month, observer and school (fitted as a random effect). A total of 5887 children aged 9–10 years participated (response rate 68%), including 1345 white Europeans, 1523 South Asians and 1570 black African–Caribbeans.

Results Compared with white Europeans, South Asians had a higher sum of all skinfolds and fat mass percentage, and their body mass index (BMI) was lower. South Asians were slightly shorter but use of optimally height-standardized indices did not materially affect these comparisons. At any given fat mass, BMI was lower in South Asians than white Europeans. In similar comparisons, black African–Caribbeans had a lower sum of all skinfolds but a higher fat mass percentage, and their BMI was higher. Black African–Caribbeans were markedly taller. Use of optimally height-standardized indices yielded markedly different findings; sum of skinfolds index was markedly lower, whereas fat mass index and weight-for-height index were similar. At any given fat mass, BMI was similar in black African–Caribbeans and white Europeans.

Conclusions UK South Asian children have higher adiposity levels and black African–Caribbeans have similar or lower adiposity levels when compared with white Europeans. However, these differences are not well represented by comparisons based on BMI, which systematically underestimates adiposity in South Asians, and in black African–Caribbeans it overestimates adiposity because of its association with height.

Keywords Ethnicity, South Asian, African–Caribbean, adiposity, obesity, body mass index

Introduction

The rising prevalence of overweight and obesity in children may have adverse long-term consequences for risks of type 2 diabetes and cardiovascular diseases, both in the UK and more widely.[1–3] In the UK, the impact of rising overweight and obesity in childhood could be particularly serious in ethnic minority groups (particularly South Asians and black African–Caribbeans), in which risks of type 2 diabetes and cardiovascular disease (conditions strongly influenced by overweight and obesity) are already high[4–9] and may be emerging in childhood and adolescence.[10–12]

It is therefore important to define the extent of adiposity in children from different ethnic groups. Although several large-scale studies have examined the extent of adiposity among UK children and/or adolescents of South Asian, black African–Caribbean and white European origin during the past 15 years, most have used body mass index (BMI).[6,7,13–16] These studies have consistently reported higher levels of BMI and adiposity in UK black African–Caribbeans than white Europeans,[6,7,13,15,16] although BMI levels in UK South Asians have been less consistent, with reports of lower,[13] similar[6,16] and higher[7] mean BMI compared with white Europeans. However, BMI is a marker of relative weight rather than adiposity, which is unreliable for population group comparisons,[17] and may well underestimate adiposity in Asian populations.[18–20] Studies using more specific measures of overall adiposity based on skinfold thickness and dual energy X-ray absorptiometry (DXA) (the latter in highly selected study populations) have suggested that adiposity levels are higher among South Asians[12,21,22] and lower among black African–Caribbeans.[21,22] However, even the largest of these studies could not reliably confirm the extent of South Asian–white European and black African–Caribbean–white European differences[22] and these patterns could not be confirmed in a small recent study of adolescents using doubly labelled water.[23] The results of these studies raised the possibility that BMI may underestimate adiposity in UK South Asian children[12,22] and overestimate adiposity in black African–Caribbean children,[22,23] though the reasons for these contrasting patterns remain unclear.

More evidence is therefore needed to clarify (i) the extent of ethnic differences in adiposity in large-scale studies, including representative populations of UK children of South Asian and black African–Caribbean origin and (ii) the extent to which BMI (by far the most widely used indicator of adiposity[17]) provides biased estimates of ethnic group comparisons and the explanations for such biases, both for South Asian–white European comparisons and black African–Caribbean–white European comparisons. We have therefore used two specific and independently measured markers of adiposity appropriate for population-based surveys, multiple skinfold thicknesses and fat mass derived from bioimpedance.[24] These were measured in a large population-based study of UK children of South Asian (including Indian, Pakistani and Bangladeshi), black African–Caribbean (including black African and black Caribbean) and white European origin, in which BMI measurements were also made. We set out to compare levels of specific adiposity markers in different ethnic groups, to determine whether BMI showed similar or contrasting patterns and (if appropriate) to identify the reasons for these contrasting patterns, separately for South Asians and black African–Caribbeans. In order to do this, we examined ethnic differences in optimally height standardized indices for each adiposity marker studied, to take account of marked ethnic differences in height previously reported (particularly between black African–Caribbeans and white Europeans.[6,7,13] We also examined the relations between BMI and specific adiposity markers in different ethnic groups.

Subjects and Methods

The Child Heart and Health Study in England (CHASE) is an investigation into the health of British school children in London, Leicester and Birmingham aged 9–10 years. Ethical approval was obtained from the relevant multicentre research ethics committee. Schools were identified for the sampling frame on the basis of pupil ethnicity, which was provided by the UK Government Department for Education and Skills. All state primary schools with between 15 and 50% pupils of white European origin within London, Birmingham and Leicester were included in the sampling frame. Two separate random samples of 100 schools were selected. The first included schools with a prevalence of between 20 and 80% of South Asian pupils, stratified by Indian, Pakistani and Bangladeshi origin; the second included schools with a prevalence between 20 and 80% pupils of black African–Caribbean origin, stratified by African and Caribbean origin. Overall, 70% of schools initially approached agreed to participate and the remaining 30% were replaced by similar schools from the sampling frame. One or two classes of Year 5 pupils in each school were invited to participate, depending on the number of pupils in the year. Parents or guardians of pupils were sent invitation letters (translated where necessary) and informed written consent was obtained for all participating children.

Physical measurements

A single survey team including three nurse observers carried out all measurements during school terms between October 2004 and February 2007; each measured approximately one-third of all children in each ethnic group and visited schools in different parts of London, Leicester and Birmingham in rotation. The observers received initial training in all measurement techniques in accordance with standard recommendations.[24] The observers' measurement performance was reviewed before the study and at regular intervals during the study. For each anthropometric measure, a single measurement was obtained for each child. Height was measured to the last complete millimetre using a portable stadiometer (Chasmors Ltd, London, UK). Weight was measured to the nearest 0.1 kg using an electronic digital scale (Tanita Inc., Tokyo, Japan). Waist circumference was measured at the mid-point between the lower margin of the ribs and the pelvic crest in the mid-axillary line. Skinfold thickness was measured in subscapular, suprailiac, biceps and triceps locations (right sided) using a Holtain skinfold caliper. Sum of all skinfolds was based on the sum of all four measurements of skinfold thickness, sum of trunk skinfolds on the sum of subscapular and suprailiac skinfolds and sum of limb skinfolds on the sum of biceps and triceps skinfolds. Leg to arm bioimpedance (right sided) was measured using the Bodystat 1500 bioimpedance monitor (Bodystat Ltd, Isle of Man, UK). Fat free mass was derived using an equation derived specifically for children of a similar age using DXA validation:[25]

$$\text{Fat free mass} = \frac{\begin{pmatrix} -7655 + 297 \times \text{height (cm)} + 125 \\ \times \text{weight (kg)} - 17.4 \times \text{bioimpedance} \end{pmatrix}}{1000}.$$

Fat mass was obtained by subtracting fat free mass from total body weight.

Pubertal status was assessed in girls using the Tanner breast development scoring system.[26]

Ethnic origin and socio-economic status

The ethnic origin of the child was defined using parental information on the self-reported ethnicity of both parents where available, or using parental information on the ethnicity of the child. In a small number of children where this information was not available (1.6% of participants), ethnic origin was defined using information provided by the child on their parental and grand-parental place of birth, cross-checked with observer assessment of ethnic origin. Children were defined as 'white European', 'South Asian', 'black African–Caribbean' or 'other ethnic origin'. 'White European' includes children whose ethnic origin was defined as 'white British', 'white Irish' and 'white European' (or a combination of these) and excludes 'white other'. 'South Asian' includes 'Indian', 'Pakistani', 'Bangladeshi' and 'Sri Lankan' (or a combination of these). 'Black African–Caribbean' includes 'black African', 'black Caribbean', 'black British' and 'black other' (or a combination of these). The 'other' ethnic group includes all other categories of individual and mixed ethnic origins. The ethnic subcategories 'Indian', 'Pakistani' and 'Bangladeshi' are restricted to children whose parents both originated in the same country; 'black African' and 'black Caribbean' groups to those who originated in the same region. Information on parental occupation provided by parents or (where not available) by participating children was coded using the SOC-2000 occupational classification.[27] Parental occupation was based on the highest SOC2000 occupation recorded for either parent.

Statistical methods

Statistical analyses were carried out using STATA/SE software (Stata/SE 10 for Windows, StataCorp LP, College Station, TX, USA). Height-standardized adiposity indices were derived using linear regression of the adiposity measure on height (both log transformed) using the whole study population to obtain the appropriate power relationship. This produces an optimally height-standardized index that is uncorrelated with height.[21] For all other analyses, physical measurements of body size and adiposity were log transformed throughout with the exception of height and fat mass percentage. Adjusted means and ethnic differences were obtained using multilevel linear regression modelling; school was fitted as a random effect to take account of the clustering of children within school. Pearson's correlation coefficients were calculated to examine the strength of correlation between the outcome variables. Spline plots were used to show the inter-relationships between adiposity measures using the MSPLINE command in Stata. Multilevel models were extended to quantify ethnic differences in log(BMI) by including an interaction between fat mass percentage or sum of all skinfolds and ethnic group. Ethnic differences in log(BMI) were converted into approximate absolute difference in BMI by multiplying the proportional differences by the expected median BMI at median fat mass percentage or sum of all skinfolds.

Expected median BMI values (kg/m^2) were estimated empirically by calculating the median BMI value within 5 percentiles either side of the median for fat mass percentage or sum of all skinfolds. Sensitivity analyses were carried out to examine the effect of adjustment for social class using SOC2000 (fitted using a nine-level categorical variable) and pubertal stage in girls (fitted using a three-level categorical variable for Tanner breast development) on the ethnic differences.

Results

Of 8690 children invited to participate in the study, 5887 (68%) participated and 5759 had complete adiposity measurements. Participation rates were similar for white Europeans, South Asians and other ethnicity (69, 72, and 70% respectively) but slightly lower for black African–Caribbean participants (66%). Numbers of participants of white European, South Asian, black African–Caribbean and other ethnicity in the study were similar ($n = 1345$, 1523, 1570 and 1321, respectively). Measurements of body size and adiposity are shown separately for boys and girls in Table 1. Girls were slightly taller and heavier than boys with a higher mean BMI, waist circumference, sum of all skinfolds and fat mass percentage. Several adiposity measures were strongly related to height in this study population (Table 2). Height was positively correlated with BMI ($r = 0.39$), waist circumference ($r = 0.49$), sum of all skinfolds ($r = 0.33$) and fat mass percentage ($r = 0.28$); these associations were observed in both sexes (data not presented). To examine ethnic differences in adiposity independently of height, corresponding adiposity measures optimally standardized for height (weight-for-height index, waist-for-height index, sum of all skinfolds index, fat mass index respectively) were derived. This height standardization removed the correlation with height for all variables so that the resulting correlation coefficients were very close to zero (Table 2). These height-standardized adiposity measures remained higher in girls than boys (Table 1).

South Asian–white European differences in adiposity

When compared with white European children, South Asians were on average shorter and lighter (Tables 3 and 4). However, both their fat mass percentage from bioimpedance and their sum of all skinfolds were higher, the latter largely reflecting higher trunk skinfolds. BMI and waist circumference, however, were both lower. In corresponding analyses with optimal height-standardized indices, similar patterns were observed. South Asian children had a higher fat mass index and a higher sum of all skinfolds index, with a consistent standardized difference for both measures (Table 4). Weight-for-height and waist measurements were both lower (though the differences, expressed as z-scores, were slightly smaller). These differences were similar for boys and girls

Table 1 Gender differences in body size measures

	Boys ($n = 2818$)		**Girls ($n = 2941$)**		**P (gender difference)**
	Mean[a]	SD[a]	Mean[a]	SD[a]	
Conventional measures					
Height (cm)	139.9	6.93	140.5	7.59	0.003
Weight (kg)[b]	35.80	1.26	36.65	1.28	<0.001
BMI (kg/m^2)[b]	18.33	1.19	18.63	1.21	<0.001
Waist circumference (cm)[b]	63.61	1.15	64.45	1.16	<0.001
Sum of all skinfolds (mm)[b]	37.17	1.68	45.88	1.59	<0.0001
Sum of trunk skinfolds (mm)[b]	17.97	1.84	23.02	1.76	<0.0001
Sum of limb skinfolds (mm)[b]	18.81	1.57	22.34	1.49	<0.0001
Fat mass percentage	27.30	9.14	30.08	9.07	<0.0001
Optimally height standardized indices					
Weight-for-height index (kg/m$^{3.4}$)[b]	11.59	1.18	11.72	1.19	0.01
Waist-for-height$^{1.4}$ index[b]	0.08	1.13	0.08	1.14	0.01
Sum of all skinfolds index (mm/m$^{3.2}$)[b]	12.77	1.62	15.59	1.56	<0.0001
Sum of trunk skinfolds index (mm/m$^{3.8}$)[b]	5.10	1.77	6.45	1.72	<0.0001
Sum of limb skinfolds index (mm/m$^{2.6}$)[b]	7.82	1.53	9.21	1.47	<0.0001
Fat mass index (kg/m$^{5.3}$)[b]	1.57	1.70	1.75	1.68	<0.0001

Means and geometric means are adjusted for age quartiles, observer, month and a random effect for school.
[a]Geometric means and geometric SDs shown for log transformed variables.
[b]Log transformed variable.

Table 2 Correlations of body size measures

	Height	Weight[a]	BMI[a]	Waist circ.[a]	Sum of all skf[a]	Sum of trunk skf[a]	Sum of limb skf[a]	Fat mass percentage	Weight-for-ht index[a]	Waist-for-ht index[a]	Sum of all skf index[a]	Sum of trunk skf index[a]	Sum of limb skf index[a]
Conventional measures													
Weight (kg)[a]	0.72												
BMI (kg/m^2)[a]	0.39	0.92											
Waist circumference (cm)[a]	0.49	0.90	0.92										
Sum of all skinfolds (mm)[a]	0.33	0.79	0.86	0.86									
Sum of trunk skinfolds (mm)[a]	0.33	0.78	0.85	0.85	0.98								
Sum of limb skinfolds (mm)[a]	0.31	0.75	0.82	0.81	0.96	0.88							
Fat mass percentage	0.28	0.73	0.82	0.79	0.82	0.80	0.79						
Optimally height standardized indices													
Weight-for-height index ($kg/m^{3.4}$)[a]	0.001	0.69	0.92	0.80	0.79	0.78	0.75	0.77					
Waist-for-height$^{1.4}$ index[a]	0.0001	0.63	0.84	0.87	0.80	0.79	0.75	0.75	0.91				
Sum of all skinfolds index ($mm/m^{3.2}$)[a]	0.001	0.58	0.77	0.74	0.94	0.92	0.90	0.77	0.84	0.85			
Sum of trunk skinfolds index ($mm/m^{3.8}$)[a]	0.001	0.57	0.76	0.73	0.92	0.95	0.82	0.75	0.83	0.84	0.98		
Sum of limb skinfolds index ($mm/m^{2.6}$)[a]	−0.0001	0.55	0.73	0.69	0.90	0.82	0.95	0.74	0.80	0.79	0.95	0.87	
Fat mass index ($kg/m^{5.3}$)[a]	0.002	0.56	0.75	0.67	0.73	0.71	0.71	0.90	0.81	0.77	0.77	0.75	0.74

Pearson correlation coefficients shown. circ. = circumference; skf = skinfolds; ht = height.
[a]Log transformed variable.

throughout, with no strong evidence of gender differences (Supplementary Tables S1 and S2 available as supplementary data at *IJE* online). The pattern of South Asian–white European differences in adiposity were generally observed for all South Asian subgroups, but there was some heterogeneity. In particular, Bangladeshis were shorter, with a higher weight-for-height index than both Pakistanis (intermediate) and Indians (Supplementary Tables S1 and S2 available as supplementary data at *IJE* online).

Black African–Caribbean–white European differences in adiposity

When compared with white European children, black African–Caribbeans were markedly taller and heavier on average (Tables 3 and 4). Their fat mass percentage from bioimpedance was higher, but their sum of all skinfolds was slightly lower, particularly reflecting lower limb skinfold measurements (Table 4). BMI was markedly higher, whereas waist circumference was very similar. However, these patterns were markedly changed by height standardization. In corresponding analyses with optimal height-standardized indices, fat mass index was similar in black African–Caribbeans and white Europeans, whereas sum of all skinfolds index was markedly lower among black African–Caribbeans, the latter reflecting differences in both trunk and limb skinfolds (Table 4). Weight-for-height index was similar in both groups, whereas waist-for-height index was lower in black African–Caribbeans. Although the greater heights and weights observed in black African–Caribbeans were particularly marked among girls, they were apparent in both genders; greater waist circumference in black African–Caribbeans was only apparent in girls (Supplementary Table S1 available as supplementary data at *IJE* online). However, differences in optimally height-standardized indices between black African–Caribbeans and white Europeans did not vary appreciably between boys and girls (Supplementary Table S2 available as supplementary data at *IJE* online). The pattern of black African–Caribbean–white European differences in adiposity were generally similar in black Africans and black Caribbeans. However, mean weight, BMI and weight-for-height index tended to be higher among black Caribbeans (Supplementary Tables S1 and S2 available as supplementary data at *IJE* online).

Relations between BMI and other adiposity markers in different ethnic groups

The relationships between BMI and specific adiposity markers (fat mass percentage and sum of all skinfolds) in different ethnic groups are shown in Figure 1. At any given level of fat mass percentage or sum of all skinfolds, South Asian children had a lower BMI than white European children. Ethnic differences in BMI at median levels of fat mass percentage and sum of all skinfolds are summarized in Table 5, with analyses summarizing the differences

Table 3 Body size measures by ethnic group

	Mean[a] (95% CI)							
	White European		South Asian		Black African–Caribbean		Other	
	$n=1345$		$n=1523$		$n=1570$		$n=1321$	
Conventional measures								
Height (cm)	139.1	(138.7, 139.5)	138.7	(138.3, 139.0)	143.0	(142.7, 143.4)	139.6	(139.2, 140.0)
Weight (kg)[b]	35.45	(34.99, 35.91)	34.45	(34.02, 34.88)	38.75	(38.29, 39.22)	36.13	(35.66, 36.61)
BMI (kg/m^2)[b]	18.36	(18.18, 18.55)	17.96	(17.79, 18.14)	18.99	(18.82, 19.17)	18.59	(18.40, 18.77)
Waist circumference (cm)[b]	64.35	(63.84, 64.85)	63.30	(62.82, 63.78)	64.30	(63.83, 64.77)	64.25	(63.75, 64.76)
Sum of all skinfolds (mm)[b]	41.25	(40.11, 42.41)	43.12	(41.97, 44.32)	39.97	(38.94, 41.03)	41.38	(40.24, 42.56)
Sum of trunk skinfolds (mm)[b]	20.08	(19.42, 20.75)	21.55	(20.86, 22.26)	19.56	(18.96, 20.18)	20.50	(19.83, 21.20)
Sum of limb skinfolds (mm)[b]	20.72	(20.23, 21.22)	21.04	(20.55, 21.54)	20.01	(19.56, 20.46)	20.45	(19.96, 20.94)
Fat mass percentage	27.46	(26.90, 28.02)	29.22	(28.66, 29.78)	29.49	(28.95, 30.02)	28.54	(27.98, 29.11)
Optimally height standardized indices								
Weight-for-height index ($kg/m^{3.4}$)[b]	11.70	(11.59, 11.81)	11.50	(11.40, 11.60)	11.66	(11.56, 11.76)	11.79	(11.68, 11.90)
Waist-for-height$^{1.4}$ index[b]	0.082	(0.082, 0.083)	0.081	(0.081, 0.082)	0.079	(0.079, 0.080)	0.082	(0.081, 0.082)
Sum of all skinfolds index ($mm/m^{3.2}$)[b]	14.44	(14.07, 14.83)	15.26	(14.88, 15.65)	12.82	(12.51, 13.13)	14.33	(13.96, 14.71)
Sum of trunk skinfolds index ($mm/m^{3.8}$)[b]	5.83	(5.65, 6.01)	6.33	(6.14, 6.53)	5.12	(4.97, 5.27)	5.88	(5.70, 6.06)
Sum of limb skinfolds index ($mm/m^{2.6}$)[b]	8.75	(8.56, 8.95)	8.96	(8.77, 9.16)	7.86	(7.70, 8.03)	8.56	(8.37, 8.75)
Fat mass index ($kg/m^{5.3}$)[b]	1.61	(1.56, 1.66)	1.71	(1.66, 1.77)	1.65	(1.60, 1.70)	1.68	(1.62, 1.73)

Means are adjusted for gender, age quartiles, observer, month and a random effect for school. 95% CI = 95% confidence interval.
[a]Geometric mean shown for log transformed variables.
[b]Log transformed variable.

Table 4 Ethnic differences in body size measures expressed as *z*-scores

	South Asian–white European			Black African–Caribbean–white European		
	Difference in *z*-score	(95% CI)	*P* (diff.)	Difference in z-score	(95% CI)	*P* (diff.)
Conventional measures						
Height (cm)	–0.06	(–0.13, 0.01)	0.08	0.54	(0.47, 0.61)	<0.0001
Weight (kg)	–0.12	(–0.19, –0.05)	0.001	0.37	(0.30, 0.44)	<0.0001
BMI (kg/m^2)	–0.12	(–0.20, –0.05)	0.001	0.19	(0.11, 0.26)	<0.0001
Waist circumference (cm)	–0.11	(–0.19, –0.04)	0.002	0.00	(–0.08, 0.07)	0.90
Sum of all skinfolds (mm)	0.09	(0.01, 0.16)	0.02	–0.06	(–0.13, 0.01)	0.09
Sum of trunk skinfolds (mm)	0.12	(0.05, 0.19)	0.001	–0.04	(–0.11, 0.03)	0.23
Sum of limb skinfolds (mm)	0.04	(–0.04, 0.11)	0.35	–0.08	(–0.15, –0.01)	0.03
Fat mass percentage	0.19	(0.12, 0.27)	<0.0001	0.22	(0.15, 0.29)	<0.0001
Optimally height standardized indices						
Weight-for-height index (kg/m$^{3.4}$)	–0.10	(–0.18, –0.03)	0.01	–0.02	(–0.10, 0.05)	0.53
Waist-for-height$^{1.4}$ index	–0.09	(–0.17, –0.02)	0.01	–0.30	(–0.37, –0.23)	<0.0001
Sum of all skinfolds index (mm/m$^{3.2}$)	0.12	(0.04, 0.19)	0.002	–0.25	(–0.32, –0.18)	<0.0001
Sum of trunk skinfolds index (mm/m$^{3.8}$)	0.15	(0.07, 0.22)	<0.0001	–0.23	(–0.30, –0.16)	<0.0001
Sum of limb skinfolds index (mm/m$^{2.6}$)	0.06	(–0.02, 0.13)	0.12	–0.26	(–0.33, –0.19)	<0.0001
Fat mass index (kg/m$^{5.3}$)	0.12	(0.04, 0.19)	0.002	0.04	(–0.03, 0.12)	0.24

Ethnic differences (expressed as *z*-scores) are adjusted for gender, age quartiles, observer, month and a random effect for school. 95% CI = 95% confidence interval.

by gender and ethnic subgroup. Overall, at the median level of fat mass percentage, South Asian children had a BMI level ~0.9 kg/m^2 lower than white Europeans; this difference was slightly larger in boys than girls and in Indian children rather than Pakistanis (intermediate) and Bangladeshis. At the median level of sum of all skinfolds, the estimate of the BMI difference was slightly smaller (~0.7 kg/m^2); again, the difference was slightly larger in boys and in Indian children. A contrasting pattern was observed in black African–Caribbean children (Figure 1, Table 5). At any given level of fat mass percentage, black African–Caribbeans and white Europeans had very similar overall levels of BMI. At any given level of sum of all skinfolds, black African–Caribbeans had slightly higher levels of BMI. Although overall BMI levels at the median level of fat mass percentage were very similar in black African–Caribbeans and white Europeans, black Africans tended to have slightly lower BMI and black Caribbeans higher BMI than white Europeans. However, the differences were small (a maximum of 0.3 kg/m^2). The higher BMI in black African–Caribbeans at the median level of sum of all skinfolds (~0.7 kg/m^2) was slightly larger in girls rather than boys and among black Caribbeans rather than black Africans. The results of these analyses were similar when optimally height-standardized markers were used.

In sensitivity analyses, the results presented were unaffected by the use of other published calibration equations for the derivation of fat-free mass from bioimpedance.[28,29] Adjustment for occupational social class and adjustment for pubertal status in girls also had no material effect on the results.

Discussion

This study demonstrates distinctive differences in body size and adiposity patterns between South Asian, black African–Caribbean and white European children. South Asian children had higher adiposity levels when defined by specific adiposity markers (skinfolds and fat mass based on bioimpedance), though their BMI was lower. These patterns were little affected by use of optimally height-standardized indices. However, the relation between BMI and specific adiposity markers differed from white Europeans; at any given fat mass percentage or sum of skinfolds, BMI was lower in South Asians than white Europeans. In similar comparisons, black African–Caribbeans had a lower sum of all skinfolds but a higher fat mass percentage; their BMI was higher. Black African–Caribbeans were markedly taller and these comparisons were markedly affected by the use of optimally height-standardized indices; their fat mass index and weight-for-height index were similar to those of white Europeans and their sum of skinfolds index markedly lower. However, at any given fat mass percentage, BMI was similar in black African–Caribbeans and white Europeans and at any given sum of skinfolds, BMI was higher in black African–Caribbeans compared with white Europeans.

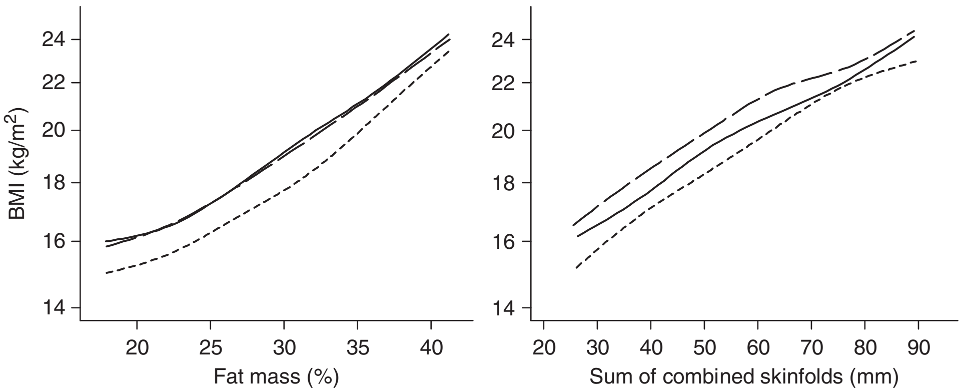

Figure 1 Interrelationships between measures of adiposity in white Europeans (solid line), South Asians (short dashes) and Black African–Caribbeans (long dashes) using median splines. Data are presented between the 5th and 95th percentiles for the variable on the horizontal axis. The vertical axis is on the log scale

Table 5 Estimated ethnic differences in BMI at median adiposity (fat mass percentage or sum of all skinfolds) levels in whole study population: for all children, by gender and by South Asian and Black African–Caribbean ethnic subgroups

	Estimated absolute difference in BMI (95% CI)	
Explanatory variable	South Asian–white European	Black African–Caribbean–white European
Fat mass percentage		
All	−0.89 (−1.02, −0.76)	−0.05 (−0.17, 0.08)
Boys	−0.92 (−1.09, −0.75)	−0.06 (−0.23, 0.11)
Girls	−0.84 (−1.04, −0.65)	−0.02 (−0.22, 0.18)
Indian	−0.97 (−1.15, −0.79)	–
Pakistani	−0.89 (−1.06, −0.72)	–
Bangladeshi	−0.77 (−0.98, −0.56)	–
B African	–	−0.30 (−0.44, −0.15)
B Caribbean	–	0.30 (0.13, 0.47)
Sum of all skinfolds (mm)		
All	−0.69 (−0.80, −0.58)	0.66 (0.55, 0.78)
Boys	−0.77 (−0.91, −0.63)	0.64 (0.49, 0.79)
Girls	−0.67 (−0.84, −0.51)	0.68 (0.51, 0.85)
Indian	−0.90 (−1.05, −0.74)	–
Pakistani	−0.73 (−0.88, −0.58)	–
Bangladeshi	−0.44 (−0.62, −0.26)	–
B African	–	0.51 (0.38, 0.64)
B Caribbean	–	0.83 (0.68, 0.98)

Estimated ethnic differences were evaluated at the median level of adiposity (fat mass percentage or sum of all skinfolds) and are adjusted for gender (combined analysis only), age quartiles, observer, month, ethnicity, an interaction term between ethnicity and the explanatory adiposity variable and a random effect for school. Ethnic differences presented separately for boys and girls were from a stratified analysis by gender. 95% CI = 95% confidence interval.

Relation to previous studies

The higher levels of adiposity observed in UK South Asian children in the present study, based on specific adiposity markers (skinfolds and fat mass), are consistent with those described in earlier studies based on skinfold measurements,[21] bioimpedance[11] and DXA scanning in highly selected populations.[12,22] However, findings even in the largest previous study were not consistent in prepubertal children[22] and a small recent study of adolescents using doubly labelled water did not find appreciable differences.[23] The observation that mean BMI levels in South Asians were low in relation to specific adiposity measures is consistent with observations made in the earlier DXA studies.[12,22] However, only one small DXA-based study has examined the relationship between body fat and BMI in UK South Asian children, suggesting that they have higher fat mass at a given BMI than white Europeans.[12] The similar or lower levels of adiposity observed in UK black African–Caribbeans in the present study based on specific adiposity markers are consistent with earlier reports based on skinfold measurements[21] and a study based on DXA measurements, though differences were only marked in adolescents.[22] The observation that mean BMI levels in black African–Caribbean children were high in relation to specific adiposity markers is consistent with observations made in earlier studies using skinfold measurements[21] and DXA.[22] The present report confirms these earlier observations in substantially larger and more representative South Asian and black African–Caribbean populations than those in most previous studies, using two independent and specific adiposity markers (skinfolds and fat mass based on bioimpedance). Moreover, it goes beyond earlier reports in UK children in its exploration of the reasons why BMI underestimates adiposity in South Asians and overestimates adiposity in black African–Caribbeans. In particular, the finding that an optimally height-standardized weight-for-height measure is not higher among black African–Caribbeans than white

Europeans (in contrast to BMI) is novel. The observation that black African–Caribbeans have a similar body fat percentage (and possibly a lower skinfold thickness) at a given BMI has not previously been reported in UK children, though it is consistent with reports from the USA showing that African Americans have either similar[30] or lower body fat levels at a given BMI.[31,32]

Implications for comparisons of adiposity between ethnic groups

The results presented in this report suggest that valid comparisons of adiposity between children of South Asian, black African–Caribbean and white European origin require the use of specific measures of adiposity (in the present context, bioimpedance and skinfold measures). Although BMI is a useful marker of the degree of adiposity in individuals[17]) it provides misleading comparisons both of South Asian–white European and black African–white European comparisons, for different reasons. In the case of South Asian–white European comparisons (in which fat mass percentage and sum of all skinfolds were higher in South Asians, whereas BMI was lower) the discrepancy appeared to reflect the higher levels of fat mass in South Asians at a given BMI (Figure 1, Table 5). The results were little affected by the use of optimally height-standardized indices, suggesting that height did not play an important part in these differences. In the case of black African–Caribbean–white European comparisons (in which weight-for-height index, fat mass index and sum of all skinfolds were similar or lower, whereas BMI was higher), this discrepancy primarily reflected the markedly greater height of black African–Caribbean children, and the strong association between BMI and height in this age-group, which we and others have previously noted.[21,33] However, no appreciable difference in the BMI–body fat percentage association between black African–Caribbean and white European children was noted.

The results suggest that earlier studies using BMI to compare adiposity levels in South Asian and white European children[6,7,13–16] may well have underestimated adiposity in South Asians. For BMI-based comparisons in the 9- to 10-year-age group, our data suggest it would be necessary to add 0.7 kg or 0.9 kg/m^2 (depending on whether skinfolds or bioimpedance measurements are used for reference) to BMI values in South Asians, to take account of their higher body fat at a given BMI level; these estimates are somewhat smaller than the average BMI difference at an equivalent body fat reported for Asian and white European adults (1.4 kg/m^2 in males and 1.3 kg/m^2 in females).[19] In contrast, earlier studies using BMI to compare adiposity levels in black African–Caribbeans and white European children are likely to have overestimated adiposity in black African–Caribbeans, particularly in those studies in which black African–Caribbeans were appreciably taller.[6,7,13]

Ethnic differences in adiposity: public health implications

UK South Asian children have higher levels of general adiposity (based on the consistent findings of bioimpedance and skinfold thickness measurements) than white Europeans by 9–10 years of age. The higher body fat percentage in South Asian children ($\sim$2%, 0.2 standard deviations) may well persist into adult life and have appreciable adverse effects on the already higher risks of type 2 diabetes, insulin resistance and cardiovascular disease among South Asians[4–7] from childhood onwards.[34] These effects could be particularly large if South Asians are particularly sensitive to the metabolic consequences of adiposity, as previous studies have suggested,[10,35,36] and emphasize the need for identifying and controlling the determinants of higher levels of adiposity among South Asian children, potentially including childhood physical activity,[37] childhood nutrition,[38] fetal nutrition[39] and biological selection effects.[40] Although our study does not suggest that adiposity is more marked in black African–Caribbean children than white Europeans, overall adiposity levels in UK children are high and increasing[6,7] and the risks of type 2 diabetes in black African–Caribbean adults are high.[6–8] The prevention of obesity among black African–Caribbean children therefore remains an important public health priority.

Strengths and limitations

The strengths and limitations of this investigation require careful consideration. The study included two independent and valid measurements of adiposity (skinfold thickness and bioimpedance),[6,41] as well as relative weight measures. Although the validity of the bioimpedance depends on the validity of the equation used to derive fat free mass,[41,42] we used data from the largest available calibration study, which used DXA measurements as the basis for deriving fat free mass estimates.[25] Although concern has been raised about the validity of DXA as a gold standard measure of body composition,[43] we obtained similar results using other equations based on smaller calibration studies using doubly labelled water.[28,29] Although no ethnic-specific calibration equations are available for deriving fat free mass from bioimpedance in different ethnic groups, the results of a recent study applying ethnic group-specific equations in adolescents using leg–leg bioimpedance suggested that any bias introduced would have led to underestimation of South Asian–white European differences in adiposity.[23] However, the consistency of the South Asian–white European adiposity differences observed with bioimpedance and skinfold measurements suggest that such biases are likely to be limited. Although analyses were based on a single assessment of adiposity and relative weight in each subject, this allowed the recruitment of a larger number of subjects than would otherwise have been possible, increasing statistical efficiency and power and the precision of ethnic group comparisons. The investigation provided balanced and representative samples of South Asians and black African–Caribbeans drawn from schools from three UK cities, which together account for over two-thirds of South Asians and black African–Caribbeans living in the UK. The study design allowed ethnic group comparisons to be made within schools, minimizing the influence of confounding, particularly by social factors. Potentially relevant confounding factors including socio-economic position and pubertal status in girls (the only gender in which this would have been relevant at 9- to 10-year-olds)[44–46] were assessed and had little or no effect on the results observed.

Conclusions

Adiposity levels (defined using skinfold thickness and bioimpedance) are higher in UK South Asian children and are similar or lower in UK black African–Caribbean children when compared with white Europeans. BMI provides misleading comparisons of adiposity between these groups, because it underestimates body fat in South Asians and is increased by the greater height of black African–Caribbeans.

Supplementary Data

Supplementary data are available at *IJE* online.

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Conflicts of interest: None declared.

KEY MESSAGES

- Adiposity levels (based on bioimpedance and skinfold thickness) are higher in UK South Asian children than in white Europeans and are similar or lower in UK black African–Caribbean children.
- BMI systematically underestimates adiposity in South Asian children because fat mass is systematically lower at a given BMI than for white Europeans.
- BMI systematically overestimates adiposity in black African–Caribbean children because it is associated with height, which is markedly greater in black African–Caribbeans.

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Commentary: Is there a best index of weight for height?

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Nightingale *et al*.[1] used skinfold thicknesses and body fat from bioelectrical impedance as measures of adiposity and compared body size and composition among groups of UK children from three different ethnic origins: South Asian, black African–Caribbean and white European origins. The adiposity measures, along with body mass index (BMI) and a height-standardized weight-for-height index were all compared across the three race-ethnic groups. Nightingale *et al*. found that the results of such comparisons differed depending on whether they used adiposity measures or BMI or a height-standardized index. This finding led them to question the use of BMI to compare adiposity across race-ethnic groups of children.

Interest in the problem of comparing anthropometric data between different race-ethnic groups of children has a long history. In a study published in 1951, Greulich[2] compared the growth data collected in 1947 from a representative sample of Guamanian (Chamorro) children from Guam with data from a slightly earlier Brush Foundation study of a sample of affluent white children from Cleveland Ohio. The Guamanian children, who had been subjected to hardships and deprivation during the war and the Japanese occupation of Guam, were both shorter and lighter than the Cleveland children of the same age. To put the weights of the children on a comparable scale, given the height difference, Greulich chose what he termed the 'height–weight index' (the ratio of weight to height). Using this index, he concluded that the Guamanian children were underweight for height relative to the Cleveland children, which he attributed in part to genetic differences between the Micronesian children of Guam and the children of European ancestry in Cleveland, as well as to the deprivations suffered by the Guamanians during the war. He also concluded that, although both boys and girls of Guam had suffered growth retardation in comparison with the Cleveland children, the relative effects had been greater for boys, 'consistent with the view that the human male is less successful than the female in withstanding the rigors of an unfavourable environment'.

When Gavan[3] examined the same data using a linear regression of weight on height instead of a weight–height index, he came to conclusions almost completely opposite to those reached by Greulich. Gavan's analyses found that the relation of weight to height in the regression model was the same for all four groups (the Guamanian boys and girls and the Cleveland boys and girls) and concluded that although the Guamanian children were clearly shorter than the Cleveland children at a given age, 'the Guam children are no more underweight for their stature