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RESEARCH ARTICLE

REVISED Differences in total and regional body fat and their association with BMI in UK-born White and South Asian children: findings from the Born in Bradford birth cohort [version 3; peer review: 2 approved, 1 approved with reservations]

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Abstract

Background: Body mass index (BMI) is commonly used as a proxy to determine excess adiposity, though this may underestimate fat mass (FM) in individuals of South Asian (SA) heritage. SA tend to have greater central adiposity than white people, which is associated with a higher risk of cardiometabolic disease. In this cross-sectional study, we aimed to determine the differences in total and regional FM using Dual-energy X-ray absorptiometry (DXA), and to see if any differences in FM varied by BMI category in UK-born white and SA children aged ~9 years.
Methods: Anthropometric measurements and DXA scans were undertaken from 225 white and 269 SA children from the Born in Bradford cohort study. Linear regression was used to assess ethnic differences in total body fat percent and total and regional FM.
Results: Although mean BMI was similar, compared to white children, the proportion of SA children who were overweight or obese was ~10% higher, and the proportion with > 35% total body fat (TBF) was 22% and 16% higher in boys and girls respectively. Mean TBF% was greater in SA children compared to white children in the same BMI category. Fat mass index (FMI) was higher in all body regions in SA children in all BMI categories; as was total and truncal FMI in healthy

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	1	2	3
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and overweight, but not obese, SA children..
Conclusions: Greater TBF% and total and regional FM in SA children suggests they may be at greater risk of future cardiometabolic disease at a BMI level below the obesity threshold. However, our sample size was small, and results may be influenced by selection bias and confounding; our findings need to be replicated in a larger study.

Keywords
Ethnicity, DXA, adiposity, BMI, fat mass

Any reports and responses or comments on the article can be found at the end of the article.

This article is included in the Born in Bradford gateway.

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Author roles: Santorelli G: Conceptualization, Data Curation, Formal Analysis, Methodology, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **West J**: Conceptualization, Methodology, Writing – Review & Editing; **Yang T**: Writing – Review & Editing; **Wright J**: Funding Acquisition, Writing – Review & Editing; **Bryant M**: Writing – Review & Editing; **Lawlor DA**: Funding Acquisition, Methodology, Writing – Review & Editing

Competing interests: DAL has received support from Medtronic Ltd and Roche Diagnostics.

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REVISED **Amendments from Version 2**

Differences between version 2 and 3 are (1) an error in the abstract of the difference in the proportion of SA children with overweight/obesity compared to White children has been changed from 20% to 10%; (2) in the Strengths and Limitation section of the Discussion we have reiterated that any difference in overweight and obesity status between the two ethnic groups did not reach statistical significance; and (3) changed the words 'early menstruation' to 'puberty timing'.

Any further responses from the reviewers can be found at the end of the article

Introduction

Greater adiposity has been shown to increase the risk of type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD) in adults[1–3] and children[4–8]. Risk of cardiometabolic disease is greater among those of South Asian (SA) heritage, who for a given body mass index (BMI) have greater total and central adiposity and are more likely to be insulin resistant and have CVD risk factors compared to White European adults[9–11] and children[12–15]. Specifically, it is visceral fat, which is located in the trunk, rather than subcutaneous fat, that has been consistently associated with a higher risk of cardiometabolic disease independently of total fat[16]. Thus, truncal obesity may confer a greater risk of morbidity whereas subcutaneous adipose tissue in the gluteofemoral region has been shown to be potentially protective[16]. Further, the android/gynoid FM ratio has been shown to be predictive of cardiometabolic dysregulation in both adults[17] and children[18–20].

Excess adiposity is commonly determined using BMI. Though BMI is a weight-based index that cannot distinguish between fat mass (FM) and lean mass (LM), in adults and children its correlations with FM are strong leading to similar associations of BMI and FM with cardiovascular risk factors[5]. For example, amongst 5,335 participants in a UK prospective study, BMI, DXA-determined FM and waist circumference were strongly correlated with each other (r=0.89 to 0.94). Further, their associations with fasting glucose, insulin, lipids and blood pressure at age 15 to 16 were highly consistent[5]. However, using BMI alone may underestimate FM in people of SA heritage, which has led to suggestions that BMI cut-points be adjusted in Asian adults[21] and children[15].

Studies conducted using more advanced methods to accurately quantify adiposity using Dual-energy X-ray absorptiometry (DXA) in different UK ethnic groups have found that South Asian children have significantly more total body fat compared to white children[15,22], but to our knowledge none have reported ethnic differences in regional FM.

The aims of this study were to (i) determine the magnitude and direction of any differences in total and regional FM measured using DXA scans, and (ii) explore whether any differences in total and regional FM vary by BMI category, in UK-born white and SA-origin children aged approximately 9 years.

Methods

Participants and setting

This cross-sectional study used data obtained from participants of the Born in Bradford (BiB) multi-ethnic pregnancy and birth cohort study, details of which have been described elsewhere[23]. Briefly, 12,453 pregnant women across 13,733 pregnancies were recruited between March 2007 and December 2010, resulting in 13,858 births. In 2017, a follow-up study of BiB participants was launched[24], and recruitment is expected to continue to June 2021. Briefly, the main objectives were to (i) investigate the determinants of child social and emotional wellbeing, (ii) identify the determinants of healthy growth and of adiposity and cardiometabolic health, and (iii) investigate the determinants of cognitive and sensorimotor development. The minimum effect sizes detectable for a range of outcomes were calculated based on expected participation. Families were invited to participate via a letter which included information sheets, followed by a telephone call from a BiB researcher. Assessments were conducted on a mobile health research bus or, if preferable to participants, via home visits, appointments in community locations, or through telephone or postal questionnaires. The health research bus was loaned from the University of Birmingham between February 2017 to June 2018. It comprised a procedure room, sample room and scanner room, and was equipped with a DXA machine, benchtop refrigerated centrifuge, fridge, and freezer. As the DXA scans could only be conducted on the health research bus, it was at various times located in four different areas of the city to increase the catchment area.

Ethical considerations

Ethical approval was granted by the National Health Service Health Research Authority Yorkshire and the Humber (Bradford Leeds) Research Ethics Committee (reference: 16/YH/0320). Informed consent for the data collection was provided by the child's caregiver at recruitment to the BiB cohort study, but parents were informed that they could opt-out consent for measures collected in the follow-up study at their assessment appointment.

Scan acquisition and variables

During the loan period of the mobile health research bus (February 2017 to June 2018), children who visited the bus were offered a DXA scan; scans were not available to those who were visited at home or in other community locations. Whole body scans were performed using the Lunar iDXA (GE Healthcare, Madison, WI, USA) by trained research nurses following study protocols describing how to perform daily checks and calibrations, the preparation of the study participant and the scanning procedure. Scans were delivered using the appropriate mode (paediatric or adult) and provided data on total and regional bone mineral content, FM and LM. For these analyses, we were interested total body fat percent (TBF%), and total, trunk, android, gynoid, arm and leg FM (kg). Regional boundaries were automatically demarcated using enCORE software version 14.0 and there were no instances of children not fitting within the scan field. The trunk region includes the neck, chest, abdominal and pelvic areas; the leg region includes the legs

and lateral hip area; and the arms includes arms and shoulders. The android region is totally enclosed within the trunk and is defined the area between the ribs and the pelvis; the gynoid region includes the hips and upper thighs and overlaps both the leg and trunk regions.

Anthropometric measurements

At the DXA scan appointment, height was measured to the nearest millimetre using the Leicester Height Measure and weight was measured to the nearest 0.1 kg using Tanita Body composition analyser SC-240. All measurements were taken by trained research assistants following standard operating procedures which described how to prepare and position the participants for height and weight measurements and how to record measurements accurately to reduce errors. BMI was calculated as weight/height^2 (kg/m^2) and converted to age- and sex-adjusted z-scores by comparison to the UK90 reference data[25]. The proportion of children who were categorized as having overweight/obesity and obesity were defined as those with a BMI >85th and 95th centiles, respectively. TBF% was categorised into 15–24%, 25–34% and 35+%.

Ethnicity

Ethnicity was self-reported by the mother when completing her baseline questionnaire in pregnancy and was used to define the ethnicity of her child based on UK Office of National Statistics guidance using the same classification as the 2001 UK census[26]. We defined white ethnicity as those who identified as White British and White Other; SA was assigned to those of Pakistani, Indian and Bangladeshi heritage.

Other measurements

To explore whether the DXA subsample included in these analyses were selected in a way that might introduce bias, we compared the following characteristics between the subgroup of white and SA children included in this study with white and SA mother and offspring dyads recruited to the full BiB cohort: maternal ethnicity, maternal age, maternal educational attainment, parity, IMD, smoking in pregnancy and early pregnancy BMI (based on height collected at the baseline questionnaire, and weight at pregnancy booking); and offspring sex, gestational age at birth, and birth weight (obtained from the hospital maternity system).

Statistical analysis

P-values for differences in anthropometric and DXA measures between ethnic groups were calculated using chi-squared or t-tests. Pearson's pairwise correlation was used to calculate the correlation between BMI and the DXA parameters. To enable comparison between BMI and FM, we accounted for body composition by normalising total and regional FM for height (FM/height^2). Age-adjusted linear regression was used to assess ethnic differences in total and regional FMI by BMI category (healthy=BMI ≤85th centile; overweight>85th to ≤95th centile; obese>95th centile). FMI outcomes were positively skewed, but we found their residuals compared well with those for BMI and in the main analyses did not transform FMI measures. We did check whether transforming to logged FMI made important differences to our findings and found that it did not (all regression coefficients and corresponding P-values were essentially the same for transformed compared to untransformed FMI variables). Results are stratified by ethnicity and sex. All analyses were performed using STATA/SE v17.0 (StataCorp LP, College Station, TX, USA).

Results

A flow chart of the study sample is presented in Figure 1. Between February 2017 and June 2018 (reflecting the loan period of the health research bus), 4,554 children aged ~9 years were invited to participate in the follow-up, and 2,557 consented. Of these, 1,010 consented to a DXA scan. The scans were not performed on 469 of these children due to participant or research logistical and other issues, leaving a total of 541 children who received a scan. Of these, 225 were white, 269 were SA, 35 were of other minority ethnicity groups, and ethnicity data were missing for 12 children. As there were very few children of other ethnic minority groups, analyses of the DXA data were restricted to white and SA children only.

Differences in key characteristics of those who had a DXA scan compared to the full BiB cohort are presented in Table 1. Within ethnic groups, the DXA sample comprised around 4% of the full cohort for white and SA participants, and 3% of other ethnic minority groups. Compared to the full BiB cohort, mothers of white children who had a DXA scan were older, more likely to live in an affluent area, be educated to degree level and less likely to have smoked during pregnancy. The birthweight and the proportion of males in other minority ethnic groups was greater in those who had a DXA scan compared to those who did not. There was more missing data on parity in white and SA children in the DXA sample, whereas participants in other ethnic groups who did not have a scan had a higher proportion of missing data for educational attainment and smoking during pregnancy (see Table 1).

A summary of anthropometric and DXA measurements of the sample included in these analyses are presented in Table 2. On average, SA boys were taller and heavier than white boys, but SA and white girls were similar in terms of stature and weight. Although mean BMI was comparable between ethnic groups (boys: white 17.5 kg/m^2, SA 17.9 kg/m^2, P=0.317; girls: white 18.1 kg/m^2, SA 18.2 kg/m^2, P=0.817), a larger proportion of SA children were defined as living with overweight/obesity compared to their white counterparts (boys: 39.6% vs 29.1%; girls: 36.0% vs 27.8% of girls). Figure 2 shows the distribution of BMI in both ethnic groups. The small sample sizes mean that the histogram bins are not smooth, but there is some evidence of right skewness in both ethnic groups. We would expect skewness to be greater in SA children given their higher proportion of overweight/obesity, but it is slightly larger in white children (skewness coefficient 0.79 in SA and 1.15 in white). This is likely due to the small sample size and it can be seen in Figure 2 that there is a greater proportion of SA children than white children above the threshold used to define overweight or obesity. The median difference in total FM in SA children

compared to white children was 2.3 kg for boys and 2.1 kg in girls. SA children had on average a higher TBF% than white children, and the proportion with over 35% body fat was substantially greater: white boys 15.4%; SA boys 37.5%; white girls 37.0%; SA girls 52.8%. Figure 3 shows mean TBF% by BMI category in each sex and ethnic group and demonstrates higher TBF% in girls compared with boys and in SA compared with WB in all three categories of healthy weight, overweight and obesity. It also shows that in each sex and ethnic group TBF% was increased across the three BMI categories. BMI and all DXA measurements were highly correlated with each other in both ethnic groups (Table 3).

Figure 4 shows the age-adjusted coefficients for total and regional FMI in SA compared to white children, by BMI category. SA boys and girls with a healthy weight or who were overweight had a higher FMI overall and in each compartment compared to white boys and girls in the same BMI category. In children with obesity, total body and truncal (including android and gynoid) FMI was higher in SA children compared to white children, though statistical significance at the 5% level was not reached. The difference in FMI between white and SA girls was greater in those who were overweight compared to those living with obesity.

Discussion

We have demonstrated some evidence of ethnic differences in the distribution and amount of directly measured total and regional adiposity, and their relationship with established categories of BMI. Whilst no statistically significant difference in mean BMI was observed between white and SA children, a greater proportion of SA girls and boys were overweight and obese compared to their white counterparts and on average SA children had higher TBF%, with over one-third of boys and half of girls having >35% TBF. Age-adjusted coefficients in FMI indicate higher total and regional fat in SA compared with white children. A previous study of the BiB cohort at 4–5 years found that triceps skinfolds – an indicator of peripheral fat – was lower in SA boys and girls compared to white children[27]; this contrasts with the higher arm and leg FMI observed in SA children in the present study, which may indicate that in addition to greater central adiposity, SA children may also be susceptible to increased peripheral adiposity as they grow.

Our findings of ethnic differences in TBF% fat but not BMI in white and SA children is consistent with other UK studies which measured adiposity using precise techniques[15,22] thereby adding further evidence that using BMI alone may underestimate

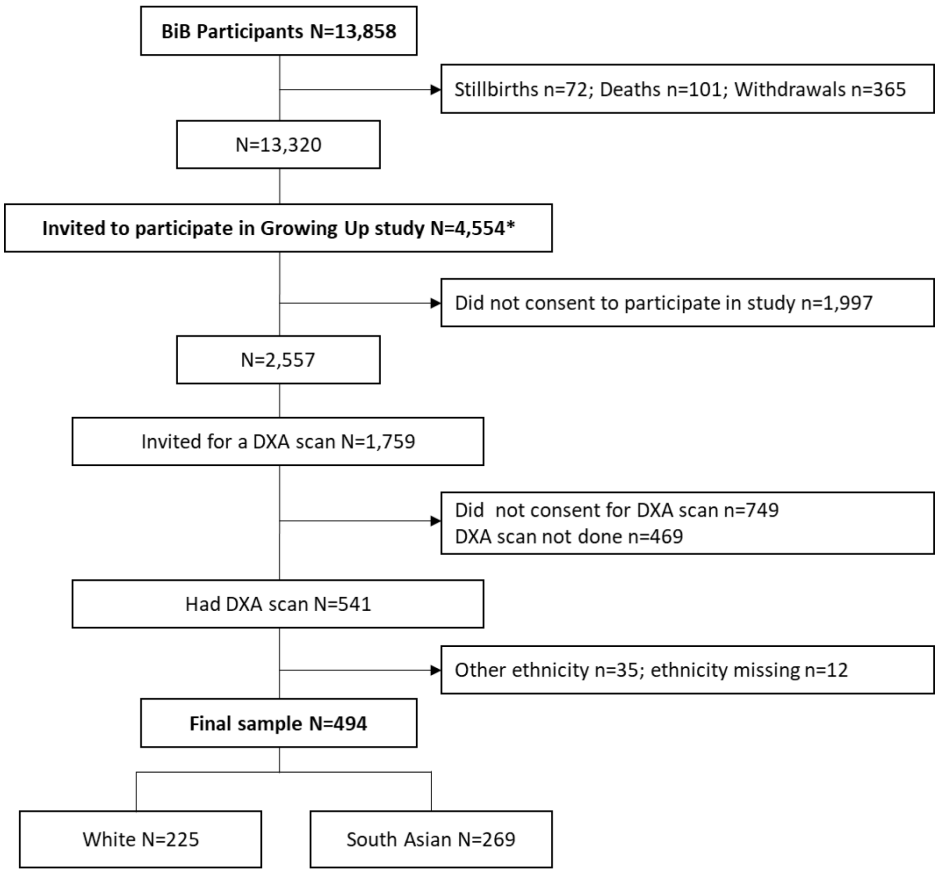


Figure 1. Flow chart of study sample. * Number invited between February 2017 and June 2018.

Table 1. Comparison between the full BiB cohort[1] and the DXA scan sample. Values are mean (SD), median (IQR) or n (%).

	White		South Asian		Other ethnic group	
	Full cohort	DXA sample	Full cohort	DXA sample	Full cohort	DXA sample
	N=5,009	N=225 (4.3%)	N=6,249	N=269 (4.1%)	N=1,134	N=35 (3.0%)
Maternal characteristics						
Age (years)	26.7 (5.9)	30.3 (6.1)	28.0 (5.1)	28.4 (5.0)	28.0 (6.0)	29.7 (5.6)
Parity						
Nulliparous	2,276 (45.4)	100 (44.4)	1,926 (30.8)	67 (24.9)	433 (38.3)	11 (31.4)
Multiparous	2,461 (49.1)	104 (46.2)	3,991 (63.9)	172 (63.9)	598 (52.7)	21 (60.0)
Missing	272 (5.4)	21 (9.3)	332 (5.3)	30 (11.2)	103 (9.1)	3 (8.6)
IMD						
1 (most deprived)	2,405 (48.0)	89 (39.6)	4,634 (74.2)	201 (74.7)	806 (71.1)	23 (65.7)
2	1,216 (24.3)	65 (28.9)	1,252 (20.0)	50 (18.6)	205 (18.1)	6 (17.1)
3	716 (14.3)	30 (13.3)	215 (3.4)	14 (5.2)	71 (6.3)	6 (17.1)
4	419 (8.4)	30 (13.3)	105 (1.7)	4 (1.5)	31 (2.7)	0
5 (least deprived)	253 (5.1)	11 (4.9)	43 (0.7)	0	21 (1.9)	0
Education						
Less than degree level	3,588 (71.6)	112 (49.8)	3,867 (61.9)	155 (57.6)	408 (36.0)	17 (48.6)
Degree level	877 (17.5)	95 (42.2)	1,477 (23.6)	70 (26.0)	282 (24.9)	11 (31.4)
Missing	544 (10.9)	18 (8.0)	905 (14.5)	44 (16.4)	444 (39.2)	7 (20.0)
Smoking during pregnancy						
Yes	1,502 (30.0)	33 (14.7)	171 (2.7)	5 (1.9)	100 (8.8)	2 (5.7)
No	2,964 (59.2)	174 (77.3)	5,176 (82.8)	220 (81.8)	593 (52.3)	27 (77.1)
Missing	543 (10.8)	18 (8.0)	902 (14.4)	45 (16.4)	441 (38.9)	6 (17.1)
BMI (kg/m^2)	26.7 (6.0)	26.2 (5.1)	25.5 (5.4)	25.7 (4.8)	26.3 (5.6)	27.3 (6.1)
Missing, n (%)	862 (17.2)	37 (16.4)	1,247 (20.0)	63 (23.4)	514 (45.3)	8 (22.9)
Child characteristics						
Male	2,583 (51.6)	117 (52.0)	3,204 (51.3)	144 (53.5)	282 (51.3)	24 (68.6)
Gestational age (weeks)	40 (38, 40)	40 (38, 40)	39 (38, 40)	39 (38, 40)	39 (38, 40)	39 (38, 40)
Missing, n (%)	118 (2.3)	6 (2.7)	109 (1.7)	7 (2.6)	55 (4.9)	0
Birthweight (kg)	3.33 (0.57)	3.32 (0.61)	3.12 (0.54)	3.14 (0.54)	3.22 (0.56)	3.41 (0.52)
Missing, n (%)	131 (2.6)	3 (1.3)	333 (5.3)	11 (4.1)	54 (4.8)	1 (2.9)

DXA= Dual-energy X-ray absorptiometry; IMD=Index of multiple deprivation; BMI=body mass index

[1]Born in Bradford participants who did not have a DXA scan; excludes stillbirths, death, and withdrawals.

adiposity in SA children. One of these studies, which included 339 SA and 654 white children between the ages of 6 to 18 years, reported the proportion of children in three different categories of TBF%: less than 15%, 15–25% and more than 25%, and found that a higher proportion of SA children were in the highest category[22]. When we used these definitions, we found there were no children in the lowest category, and therefore had to apply higher thresholds in our analyses. The difference in the proportion of SA compared to white children in the highest category was far greater than the previous study. There is a 15–20-year difference between the data collection of the sample in that study and ours and our results possibly demonstrate a worrying trend in the increasing adiposity in children, particularly in UK-born SA children. This is reflected in the UK National Child Measurement Programme (NCMP) figures for 4–5- and 10–11-year olds

Table 2. Participant characteristics by ethnicity and gender.

	Boys			Girls		
	White N=117	South Asian N=144	P-value	White N=108	South Asian N=125	P-value[4]
Age (years)[1]	9.1 (0.9)	9.1 (0.9)	0.981	9.2 (0.8)	9.2 (0.8)	0.923
Anthropometric measurements						
Height (cm)[1]	136.9 (6.8)	138.9 (8.2)	0.042	137.7 (7.7)	138.4 (7.9)	0.489
Weight (kg)[1]	33.2 (7.9)	35.1 (9.8)	0.089	35.3 (9.3)	35.3 (9.4)	0.682
BMI (kg/m^2)[1]	17.5 (3.1)	17.9 (3.6)	0.317	18.1 (3.4)	18.2 (3.7)	0.841
BMI z-score[1]	0.33 (1.26)	0.40 (1.50)	0.680	0.37 (1.24)	0.33 (1.44)	0.833
BMI category[2]			0.157			0.401
Healthy (<85th centile)	83 (70.9)	87 (60.4)		78 (72.2)	80 (64.0)	
Overweight (≥85th – 94th centile)	11 (9.4)	23 (16.0)		12 (11.1)	19 (15.2)	
Obese (≥95th centile)	23 (19.7)	34 (23.6)		18 (16.7)	26 (20.8)	
DXA data						
TBF%[1]	27.6 (7.1)	31.7 (7.3)	<0.001	32.1 (7.1)	35.7 (6.5)	<0.001
TBF% category[2]						
15–24%	49 (41.9)	32 (22.2)	<0.001	21 (19.4)	7 (5.6)	0.002
25–34%	50 (42.7)	58 (40.3)		47 (43.5)	52 (41.6)	
35+%	18 (15.4)	54 (37.5)		40 (37.0)	66 (52.8)	
Total body FMI[3]	4.0 (2.9, 5.8)	5.2 (3.5, 7.0)	0.001	5.3 (3.7, 7.0)	5.9 (4.4, 7.9)	0.008
Total body FM[3]	7.6 (5.4, 11.1)	9.9 (6.4, 14.6)	0.001	9.4 (6.8, 13.9)	11.5 (8.2)	0.012
Trunk FMI[3]	1.4 (1.0, 2.4)	2.1 (1.2, 3.0)	0.001	2.0 (1.3, 2.9)	2.5 (1.6, 3.8)	0.002
Trunk FM[3]	2.7 (1.7, 4.4)	3.8 (2.1, 6.1)	0.001	3.6 (2.4, 5.8)	4.7 (3.1, 7.2)	0.003
Android FMI[3]	0.16 (0.10, 0.32)	0.26 (0.13, 0.45)	<0.001	0.26 (0.14, 0.41)	0.34 (0.20, 0.57)	0.001
Android FM[3]	0.3 (0.2, 0.6)	0.5 (0.2, 0.9)	<0.001	0.4 (0.3, 0.8)	0.6 (0.4, 1.1)	0.002
Gynoid FMI[3]	0.69 (0.51, 0.93)	0.88 (0.59, 1.12)	<0.001	0.88 (0.66, 1.20)	1.01 (0.76, 1.27)	0.008
Gynoid FM[3]	1.3 (0.9, 1.8)	1.6 (1.1, 2.3)	0.001	1.7 (1.2, 2.5)	2.0 (1.4, 2.6)	0.010
Android/gynoid ratio (FM)	0.27 (0.10)	0.31 (0.12)	<0.001	0.30 (0.11)	0.35 (0.11)	<0.001
Arms FMI[3]	0.48 (0.36, 0.68)	0.62 (0.41, 0.82)	0.002	0.62 (0.45, 0.82)	0.67 (0.54, 0.89)	0.035
Arms FM[3]	0.9 (0.6, 1.3)	1.2 (0.8, 1.7)	0.006	1.2 (0.8, 1.6)	1.3 (1.0, 1.7)	0.106
Legs FMI[3]	1.75 (1.29, 2.33)	2.21 (1.53, 2.75)	<0.001	2.20 (1.63, 2.81	2.40 (1.87, 3.00)	0.025
Legs FM[3]	3.4 (2.3, 4.5)	4.2 (2.7, 5.8)	<0.001	4.1 (3.0)	4.7 (3.5, 6.0)	0.027

DXA= Dual-energy X-ray absorptiometry; BMI=body mass index (kg/m^2); TBF% = total body fat percentage; FMI=fat mass index (kg/m^2); FM=fat mass. [1]Mean (SD). [2]N (%). [3]Median (IQR). [4]Calculated using t-tests, chi-squared tests or Mann-Whitney tests, as appropriate.

over the past 15 years[28], which show a temporal increase in the proportion of children classified as obese: between 2006/07 and 2019/20, the percentage of 10–11 year olds living with obesity has increased from 16% to 19% in white children, and from 21% to 25% in SA children.

Only one other study exploring the associations of BMI with directly measured regional fat mass in UK adolescents was identified[8]. It included 2,840 children and reported similar associations between BMI and DXA FM with cardiometabolic risk factors as other studies in that it was abdominal fatness that

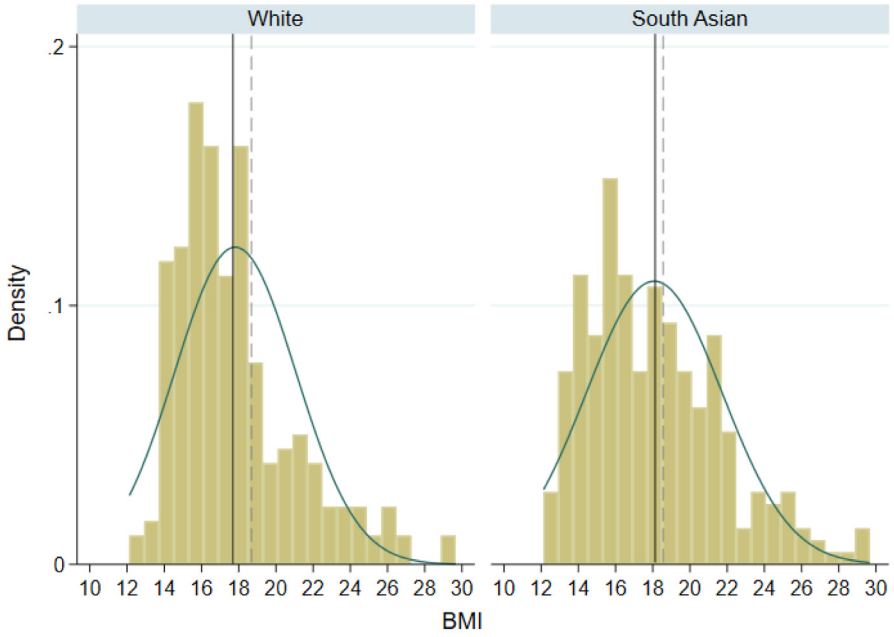


Figure 2. Distribution of BMI in white and South Asian children. Solid lines represent mean BMI in each ethnic group; dashed lines represent threshold for overweight/obesity in 9 year olds.

was the primary driver of cardiometabolic dysfunction. Again, this study was conducted in a predominantly white European population, so the increased risk of cardiometabolic disease in other ethnic groups who display greater central adiposity remains unknown. We also found that SA children had greater android and gynoid FM, and higher android/gynoid ratio compared to white children, though it is acknowledged that the confidence intervals are wide due to the sample size. A handful of studies have found that android/gynoid ratio was more strongly associated with cardiometabolic health in children[18–20]. This appears to persist into adulthood, with co-mingling of android and gynoid adiposities being associated with greater cardiometabolic risk than android or gynoid adiposity alone[17].

Our findings suggest that SA children may be at increased risk of adipose-related morbidity even when they are considered a healthy weight according to their BMI, and that their risk when overweight and obese is potentially far greater than that of white children. SA children could therefore be more metabolically unhealthy than white children in the same BMI category.

Strengths and limitations

We were able to report total and regional FM in a bi-ethnic sample measured using DXA, which is an extremely accurate method of measuring body composition. However, a limitation is that DXA cannot distinguish between visceral and subcutaneous fat, and it is the former that appears to be the primary driver of cardiometabolic dysfunction.

There were some differences between the sample in the current study and the wider BiB cohort. Whilst most characteristics were similar in SA with DXA scans and the full original cohort, white mothers whose children attended a DXA scan tended to be older, educated to degree level and less likely to smoke during pregnancy or reside in deprived areas compared to the white population in the full BiB cohort. As higher levels of obesity are associated with increasing deprivation[29], the sample in the current study may be biased in that these children were less likely to be overweight/obese than those in the full cohort. However, whilst SA children in this sample were mostly disadvantaged, two thirds of white children were also from the two most deprived IMDs. The observed differences between the full cohort and the DXA sample may also be partly driven by the proximity of participants residence to the location of the mobile unit where the DXA scans were conducted, though it was, at various times, sited at four different areas of the city to widen the catchment area. We found no difference in measurements of height, weight, or BMI z-scores in the DXA sample compared to the other participants of the follow-up study, and we see no reason why levels of adiposity would be systematically different.

We acknowledge that our study sample is small, and differences in overweight and obesity status between the two ethnic groups did not reach statistical significance. We did not adjust for any confounders or factors related to selection into the DXA study beyond age and were not able to detect differences between BMI categories or sex, with many estimates having wide confidence intervals. One potential limitation of our study is that we were not able to account for puberty, which leads to accelerated fat gain in girls[30] and has been found to occur up to three times earlier in SA girls. However, most of the girls in our sample are of Pakistani heritage (84%), and the cited

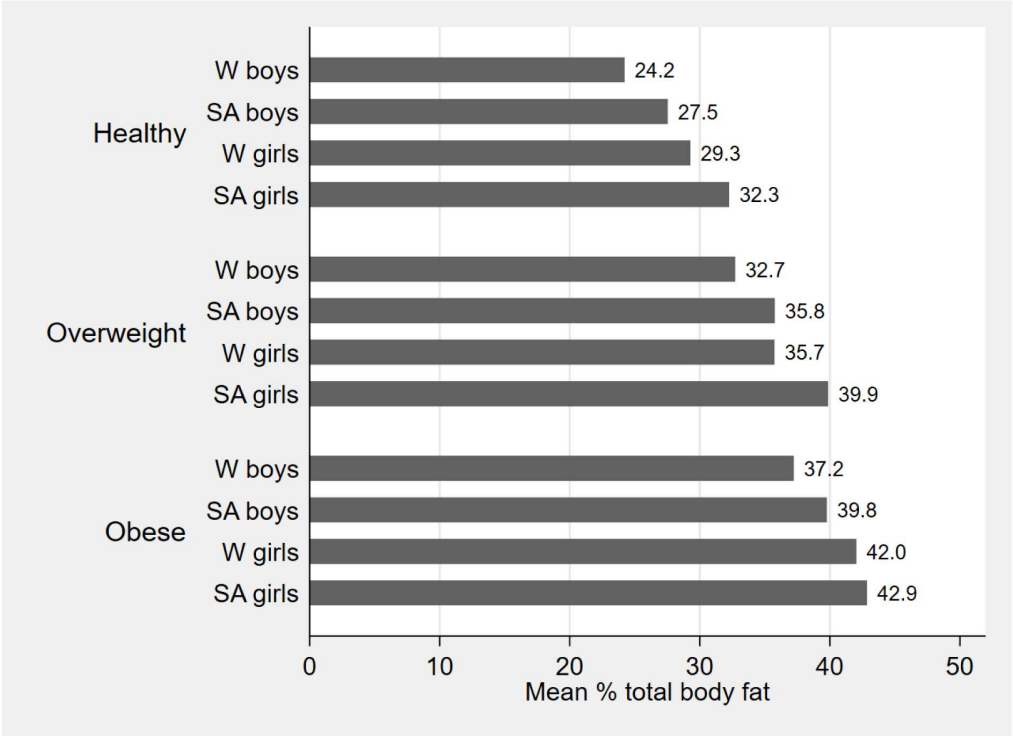


Figure 3. Mean % body fat by body mass index (BMI) category, stratified by sex and ethnic group. W=white; SA=South Asian.

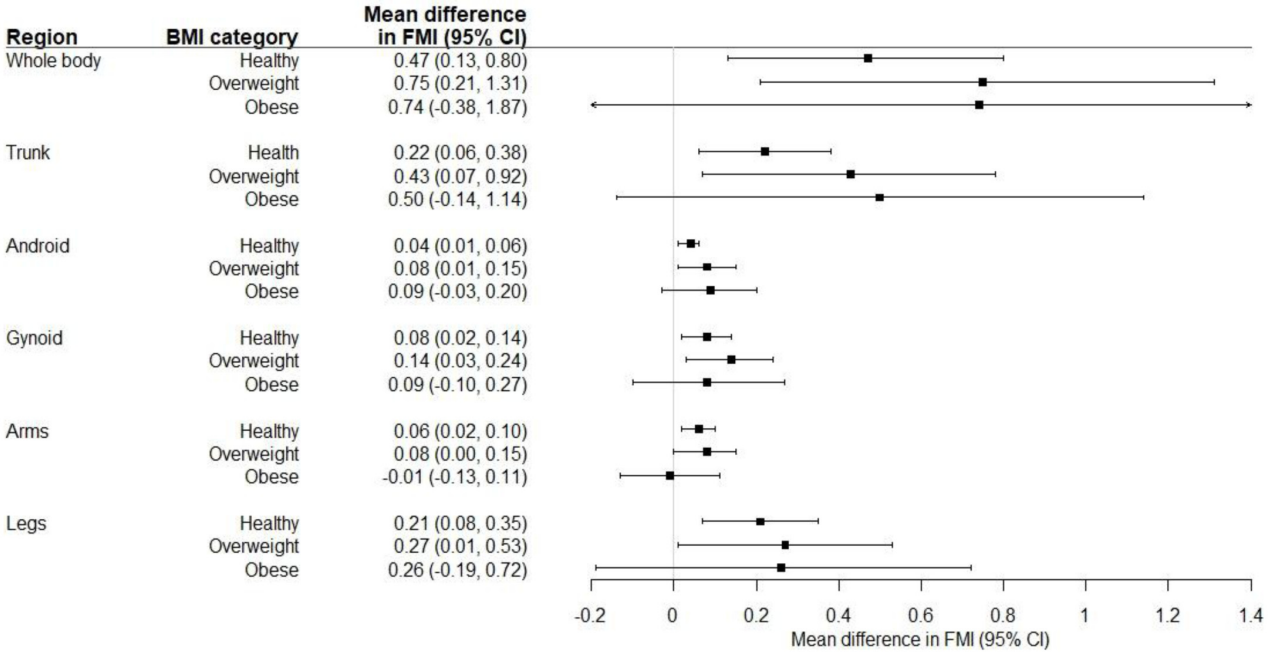
Table 3. Correlation matrix of BMI with DXA parameters in white (not italic) and South Asian (italic) children.

	BMI	FMI					
		Total body	Trunk	Android	Gynoid	Arms	Legs
BMI	1.00						
Total body	0.951 *0.950*	1.00					
Trunk	0.915 *0.931*	0.979 *0.981*	1.00				
Android	0.925 *0.936*	0.976 *0.980*	0.952 *0.989*	1.00			
Gynoid	0.904 *0.929*	0.970 *0.979*	0.964 *0.952*	0.952 *0.947*	1.00		
Arms	0.933 *0.924*	0.969 *0.971*	0.922 *0.940*	0.929 *0.943*	0.925 *0.946*	1.00	
Legs	0.935 *0.912*	0.965 *0.960*	0.895 *0.889*	0.899 *0.902*	0.924 *0.957*	0.954 *0.935*	1.00

DXA= Dual-energy X-ray absorptiometry; BMI=body mass index (kg/m^2); FMI=fat mass index (kg/m^2)

study reported much lower odds in girls of Pakistani ethnicity (1.45 [95% CI 0.9, 2.3]). In addition, the mean age of our sample is two years lower (9.2 vs 11.2), and very similar patterns of fat distribution were observed in both Pakistani boys and girls. It is therefore unlikely that puberty timing is a factor in our population.

(a) Boys



(b) Girls

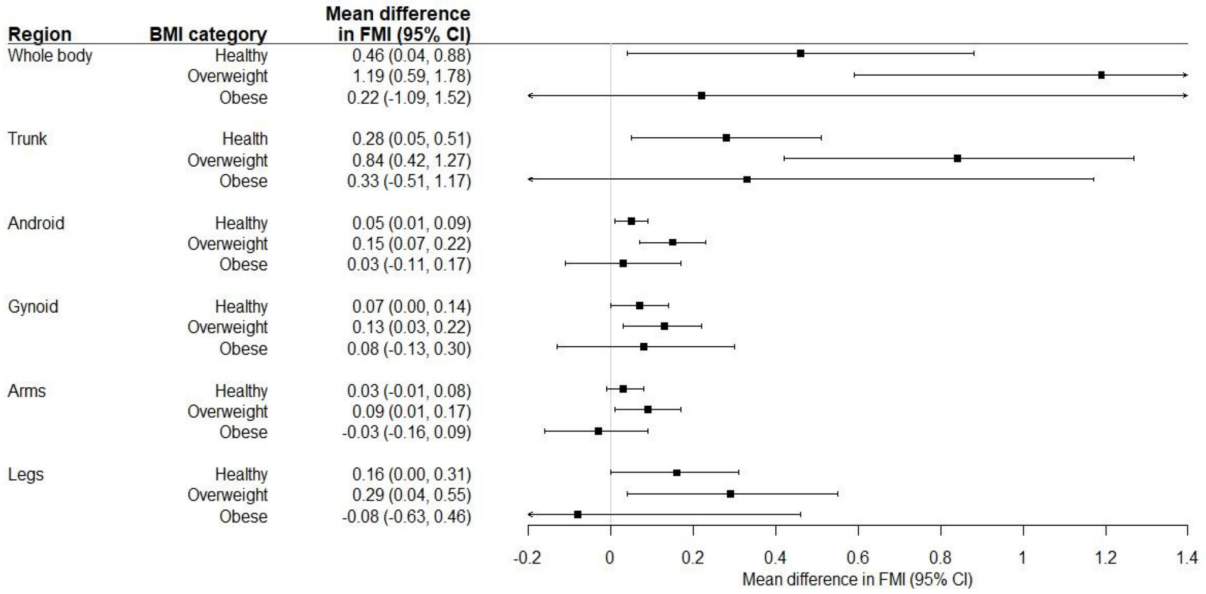


Figure 4. Coefficients (95% CI) for total and compartmental fat mass index (FMI) comparing South Asian to white children, in each body mass index (BMI) category.

Our findings need to be treated with some caution unless replicated in larger studies with greater ability to adjust for potential confounders and explore possible selection bias. Further, our sample, although representative of the region it was drawn from, may not reflect the same characteristics found in other multi-ethnic areas, including those with SA populations that are not predominantly of Pakistani heritage, as in our study. Finally, as this is a cross-sectional study, we were

not able to observe any changes in regional FM throughout childhood and adolescence.

To conclude, we have demonstrated that although there were no differences in BMI between white and SA children, SA children had greater total and regional FM compared to white children. Further, although the proportion of SA children classified as overweight and obese was higher than in white children, the differences in total and regional FM between the two ethnic groups were also observed in children of a healthy weight. The implications of this are that SA children may be at greater risk of cardiometabolic disease compared to white children with a similar BMI, and failure to recognise this at an early age may delay appropriate action, such as referrals to obesity interventions. Given the size of our study and lack of adjustment, findings need to be replicated in a larger study with power to adjust for confounders. Further research on the associations of these differences with cardiometabolic risk, and the use of ethnic-adjusted BMI thresholds where indicated to better identify children at risk, is required.

Data availability

Underlying data

Harvard Dataverse: Replication Data for: Differences in total and regional body fat and their association with BMI in UK-born White and South Asian Children: Findings from the Born in Bradford birth cohort. https://doi.org/10.7910/DVN/WEO4XI[31].

This project contains the following underlying data:

- Raw dataset including demographic and outcome variables of the sample

Data are available under the terms of the Creative Commons Zero "No rights reserved" data waiver (CC0 1.0 Public domain dedication).

Acknowledgements

BiB is only possible because of the enthusiasm and commitment of the children and parents in BiB. We are grateful to all the participants, health professionals, researchers and data teams who have made BiB happen.

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http://www.doi.org/10.7910/DVN/WEO4XI

Open Peer Review

Current Peer Review Status: ✔ ? ✔

Version 3

Reviewer Report 27 October 2023

https://doi.org/10.21956/wellcomeopenres.19736.r68170

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✔ **Rabab Alkutbe**
Research and Innovation Department, Saudi Patient Safety Center, Riyadh, Saudi Arabia

This is a detailed study attempting to determine any differences in total FM that objectively measured using DXA, and the association between the total FM and the BMI category, in UK-born white and SA-origin children aged 9 years. Although this study has many strengths, I think the below points would add value to the study:

- I think there is excellent data on the maternal characteristics' from the respondents. It would be interesting to see how these maternal characteristics could affect the children FM and body compositions.

- The author may need to apprise the socioeconomic factors by exploring more the correlation between children with obesity/OW and maternal BMI, education level, and smoking etc.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Body composition, Children, Obesity, public health, Patient Safety

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 24 October 2023

https://doi.org/10.21956/wellcomeopenres.19736.r67099

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?

Andriana Anagnostopoulou
Aghia Sophia Children's Hospital, Athens, Greece

This is an interesting article.

This is a cross sectional study which followed up children of a birth cohort of mothers.It combined anthromporphic measurements with infomrmation from dxa scan.

Some revisions suggested:

1. Did authors calculate selection bias, which they mentioned in the weaknesses part. How did they reach the sample power?

2. The BW of the SA cohort was lower than the white counterparts, as has been reported. Did they stratify according to the birth weight?

3. The authors write "Although mean BMI was similar, compared to white children, the proportion of SA children who were overweight or obese was ~10% higher, and the proportion with > 35% total body fat (TBF) was 22% and 16% higher in boys and girls respectively.".How did they reach that conclusion? Did they include other anthropometric parameters such as waist to hip ratio? That statement is not fully explained.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Paediatric cardiologist

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 18 May 2022

https://doi.org/10.21956/wellcomeopenres.19736.r49621

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Ken K. Ong
MRC Epidemiology Unit & Department of Paediatrics, Institute of Metabolic Science, School of Clinical Medicine, University of Cambridge, Cambridge, UK

The authors have responded appropriately to my comments.

Apologies for not spotting this at the previous review, but in the added Figure 2 the vertical lines indicating thresholds for overweight and obesity at age 9 years are differently situated between the two panels - these should be identical. On redrawing these figures, it would be much easier to compare the distributions if one were placed above the other (instead of side-by-side).

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology, child growth and body composition

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 04 January 2022

https://doi.org/10.21956/wellcomeopenres.19190.r46932

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?

Ken K. Ong
[1] MRC Epidemiology Unit & Department of Paediatrics, Institute of Metabolic Science, School of Clinical Medicine, University of Cambridge, Cambridge, UK
[2] MRC Epidemiology Unit & Department of Paediatrics, Institute of Metabolic Science, School of Clinical Medicine, University of Cambridge, Cambridge, UK

I am happy that the authors have addressed my previous comments. I have added a couple more comments that arise from similar points. These comments are straightforward but do need to be addressed:

Abstract results:
- "the proportion of SA children who were overweight or obese was ~20% higher". - This seems to be incorrect. The differences were 10.5% and 8.2% in boys and girls.

Strengths & Limitations Para 3:
- "We acknowledge that our study sample is small". - Add for clarification 'and differences in overweight and obesity status did not reach statistical significance'.

- "It is therefore unlikely that early menstruation is a factor in our population". - Replace 'early menstruation' with 'early puberty timing'. Menstruation is only a (relatively late) marker of

puberty timing and is not in itself a direct factor in body growth and composition.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology, child growth and body composition

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 30 Mar 2022

Gillian Santorelli

Many thanks to the reviewer for highlighting the error in the abstract, which has now been corrected. The suggested amendments to the text have also been made.

Competing Interests: None

Version 1

Reviewer Report 24 May 2021

https://doi.org/10.21956/wellcomeopenres.18370.r43559

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Ken K. Ong
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[3] MRC Epidemiology Unit & Department of Paediatrics, Institute of Metabolic Science, School of Clinical Medicine, University of Cambridge, Cambridge, UK

This cross sectional analysis of 9 year old children in the Born in Bradford cohort reports that despite having the same level of BMI, South Asian children had greater total body and central fat mass than white children.

1. However part of this difference may be because South Asian children were taller at age 9 years, especially the boys. This will contribute to having higher absolute fat mass, whereas BMI is (mostly) corrected for height. All fat mass comparisons should be adjusted for height.

2. Other UK cohorts have described that early puberty is 3x more likely in SA girls than white girls https://pubmed.ncbi.nlm.nih.gov/27672135/.[1] As puberty leads to accelerated fat gains in girls, this is another potential confounder. Do they have information on puberty status at this timepoint? If not, this should be discussed as a limitation.

3. South Asian children had a similar mean BMI to white children, yet SA have a higher prevalence of OW & OB. How can they be sure then that BMI is adequately controlled for? Discussion (line 2-3, also 1st line of the concluding paragraph) "no statistically significant difference in BMI was observed" - clarify that this refers to 'mean BMI' but that there were differences in BMI category.

4. Introduction (para 1): "gynoid fat (i.e. in the gluteofemoral region), which is subcutaneous..." This line confuses different ways to partition types of fat. Central:peripheral partitioning is quite different to visceral:subcutaneous and even intramuscular.

5. Introduction (para 2): "(BMI) is highly correlated with both (fat mass and lean mass)" - BMI is a good proxy marker of adiposity because, at least in adults, its correlations with fat mass are stronger than those with lean mass (e.g. see https://pubmed.ncbi.nlm.nih.gov/28096530/).[2] However, this is not necessarily true in children.

6. Methods: "Ethnicity was self-reported by the mother...in pregnancy" i.e. only by one parent. How big a limitation is this as a proxy for the child's ethnicity? What is the prevalence of mixed marriages in this setting?

7. Methods: The included sample here comprises only 4% of the full cohort for white and SA participants. While this was mostly for logistical issues, e.g. having visits within a certain

timescale, there was a substantial drop from visits to DXA scans: "1,759 agreed to visit the health research bus and were therefore offered a DXA scan, and (only) 1,010 agreed". This is surprising as it seems only a small step in practice to have a DXA once you visit the research bus. What were the reasons for refusing DXA and more importantly did this proportion differ by ethnicity and BMI category?

Some typo errors:

1. Methods - Anthropometry: Definition of OW and obesity should read "defined as those with a BMI >85th or >95th centile" i.e. don't confuse z-scores and percentiles

2. Statistical analyses: "presented as ... per SD change in the outcome", I think should be 'in the exposure' (not the outcome)

3. Table 2: "Mean absolute TBF%" - 'absolute' is unnecessary. What is "Avg. TBF%"? (simply 'TBF%'?)

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Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Epidemiology, child growth and body composition

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Comments on this article

Version 1

Author Response 29 Oct 2021

Gillian Santorelli

We thank Professor Ong for his review of our manuscript, and would like to respond to his comments.

Comment 1: However part of this difference may be because South Asian children were taller at age 9 years, especially the boys. This will contribute to having higher absolute fat mass, whereas BMI is (mostly) corrected for height. All fat mass comparisons should be adjusted for height.

Our response: Thank you for your guidance on this. We have calculated fat mass index for total and regional fat mass and regressed these against BMI. Accounting for height has greatly enhanced the differences observed between the two ethnic groups.

Comment 2: Other UK cohorts have described that early puberty is 3x more likely in SA girls than white girls https://pubmed.ncbi.nlm.nih.gov/27672135/.[1] As puberty leads to accelerated fat gains in girls, this is another potential confounder. Do they have information on puberty status at this timepoint? If not, this should be discussed as a limitation.

Our response: The reviewer has raised an important point. The paper referenced reports ORs for early menstruation in the fully adjusted model for a small sample SA girls are: Indian 3.66 (95% CI 2.3, 5.9), Pakistani 1.45 (0.9, 2.3) and Bangladeshi 2.15 (1.3, 3.5). Most of the SA girls in the present study are Pakistani (n=92, 83.6%), followed by Indian (n=13, 11.8%) and Bangladeshi (n=5, 4.5%) ethnic groups. Further, the mean age of children in the referenced study is two years older than those in our sample (11.2 vs 9.2 years), and older age was associated with a 5-fold increase in early menstruation. Although we do not have information on puberty status for our cohort, the small increase observed in Pakistani girls in the referenced paper and the older age of the sample suggests that early menstruation is unlikely to be a factor in our population. We have acknowledged that one of the limitations of our small study is that we did not adjust for any confounders and larger studies with the ability to adjust for potential confounders are required.

Comment 3: South Asian children had a similar mean BMI to white children, yet SA have a higher prevalence of OW & OB. How can they be sure then that BMI is adequately controlled for? Discussion (line 2-3, also 1st line of the concluding paragraph) "no statistically significant difference

in BMI was observed" - clarify that this refers to 'mean BMI' but that there were differences in BMI category.

Our response: We have included histograms to show the distribution of BMI by ethnic group. These show the difference in the degree of positive skew between the groups, with a greater number of South Asian children having a BMI greater than the threshold for overweight/obesity. We have amended the manuscript to clarify the second point as follows:
Whilst no statistically significant difference in mean BMI was observed between white and SA children, a greater proportion of SA girls and boys were overweight and obese compared to their white counterparts and on average SA children had higher TBF%, with over one-third of boys and half of girls having >35%

Comment 4: Introduction (para 1): "gynoid fat (i.e. in the gluteofemoral region), which is subcutaneous..." This line confuses different ways to partition types of fat. Central:peripheral partitioning is quite different to visceral:subcutaneous and even intramuscular.

Our response: We have amended the manuscript to:
...subcutaneous adipose tissue in the gluteofemoral region has been shown to be potentially protective.

Comment 5: Introduction (para 2): "(BMI) is highly correlated with both (fat mass and lean mass)" - BMI is a good proxy marker of adiposity because, at least in adults, its correlations with fat mass are stronger than those with lean mass (e.g. see https://pubmed.ncbi.nlm.nih.ggilliaov/28096530/). [2] However, this is not necessarily true in children.

Our response: We have amended the manuscript to reflect this as follows:
Though BMI is a weight-based index that cannot distinguish between fat mass (FM) and lean mass (LM), in adults its correlations with fat mass are stronger than with lean mass, however this is not necessarily true in children.

Comment 6: Methods: "Ethnicity was self-reported by the mother...in pregnancy" i.e. only by one parent. How big a limitation is this as a proxy for the child's ethnicity? What is the prevalence of mixed marriages in this setting?

Our response: Basing child's ethnicity on their mother's is standard in many cohort studies, for example ALSPAC and the Millennium Cohort Study, and the ONS base ethnicity on self-report but only for people aged 16 and over. In the baseline questionnaire, which was administered at recruitment to the Born in Bradford cohort study, we did not ask women their partners ethnicity, but we did ask their partner's country of birth. Of women who reported their ethnicity as White British, less than 1% had partner's who were born in South Asia. The partners of 95% of Indian ethnicity women were born in India, 99% of Bangladeshi women's partners were born in Bangladesh, and 97% of Pakistani women's partners were born in Pakistani. Further, a Labour Force Survey conducted in 2010 (https://www.equalityhumanrights.com/sites/default/files/research-paper-ethnicity-and-family-relationships-within-and-between-ethnic-groups.pdf) found that 92% of Pakistani couples

belonged to the same ethnic group as their partner. This suggests that using mother's ethnicity as a proxy for child's ethnicity is appropriate and has resulted in little misclassification.

Comment 7: Methods: The included sample here comprises only 4% of the full cohort for white and SA participants. While this was mostly for logistical issues, e.g. having visits within a certain timescale, there was a substantial drop from visits to DXA scans: "1,759 agreed to visit the health research bus and were therefore offered a DXA scan, and (only) 1,010 agreed". This is surprising as it seems only a small step in practice to have a DXA once you visit the research bus. What were the reasons for refusing DXA and more importantly did this proportion differ by ethnicity and BMI category?

Our response: As is correct ethical practice, the reasons for any participant declining to consent for specific measures, as that might seem coercive. However, many families visited the health research bus rather than other community locations simply because it was more convenient for them, irrespective of whether they consented to a DXA scan or not. We have amended the text to clarify this.

We have corrected the typo errors in the second version.

Competing Interests: No competing interests.