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Ethnic differences in skinfold thickness trajectories in children in the born in bradford 1000 cohort study provide modest support for the adipose tissue compartment hypothesis

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ABSTRACT

Background: South Asian populations have high susceptibility to cardiometabolic diseases, with high adiposity for a given Body Mass Index implicated. This study tested the adipose tissue overflow hypothesis that, compared to White Europeans, South Asians have smaller, peripheral subcutaneous adipose tissue depots.
Methods: Subscapular, triceps and thigh skinfolds were measured at 6, 12, 18, 24 and 36 months in White British (Number = 561) and British Pakistani (Number = 651) children in Bradford, England. Data were available for 1295 people. Linear spline models of the three skinfold trajectories were developed by ethnic and sex group to allow exploration of mean temporal change between groups. Models were adjusted for birthweight, length of gestation and gestational diabetes.
Results: 3-year trajectories differed between skinfold sites, with different patterns of growth observed. White British and British Pakistani children had similar adjusted subscapular skinfold thicknesses. Adjusted triceps skinfolds in British Pakistani boys and girls were mostly lower than White British children. British Pakistani children had adjusted mean thigh skinfold thicknesses mostly lower than White British children.
Conclusion: Our study provides modest support for the adipose tissue overflow hypothesis. Replication in larger birth cohorts and continuing consideration of the cardiometabolic impacts of potential differences are required.

1. Background

South Asians in the UK, and several other industrialised countries, have a higher susceptibility to diabetes and cardiovascular disease than White Europeans [1–3]. Their higher central obesity and adiposity for a given body mass index (BMI) compared to White European (henceforth White) populations is a contributor to this risk [4,5]. This fat distribution is apparently established early in life and possibly in-utero [6–10]. While South Asian newborns are smaller in most measurements, the difference for subscapular skinfold thickness, a measure of central adiposity, is small or absent compared with other measures. This has led to the concept of the 'thin-fat' South Asian phenotype, described for adults and children, i.e. low BMI but high fat content [1,5,6,11].

Both deep subcutaneous and visceral adipose tissue are positively associated with dyslipidaemia and dysglycaemia whereas adipose tissue in the lower limbs shows inverse associations with glucose and lipids [12–14].The adipose tissue overflow hypothesis proposes that, compared with White Europeans, South Asians have comparatively

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small peripheral, superficial, subcutaneous adipose tissue depots so excess energy is more readily stored in central adipose tissue depots, especially deep subcutaneous and visceral compartments [15]. The main evidence presented for this hypothesis, which has elicited much interest and citation, was the lower triceps skinfolds in South Asians, with small or no differences in subscapular skinfold at birth and in school children [15], evidence supported by our published abstract [16]. Population differences in anthropometry are thought to be partially driven by climatic factors (see discussion). Among Sniderman et al.'s recommendations for testing this hypothesis were tracking the change of fat compartment sizes in prospective cohort studies. The prediction was that the superficial, subcutaneous adipose tissue compartments in South Asians, especially in the legs, would be smaller than in White Europeans, and that the expansion of the central fat compartments would occur earlier. We measured trajectories of thigh, triceps and subscapular skinfolds to test the adipose tissue compartment hypothesis in the subsample of the Born in Bradford (BiB) cohort study in northern England [17,18].

2. Methods

Women were recruited at the Bradford Royal Infirmary at 26–28 weeks gestation when a baseline questionnaire was completed. The full BiB cohort recruited 12453 women comprising 13776 pregnancies between 2007 and 2010 and was broadly characteristic of the city's maternal population in terms of age, deprivation and ethnicity [18]. The subsample, known as BiB1000, was recruited between August 2008 and March 2009 with examinations of children at approximately 6, 12, 18, 24 and 36 months of age [17]. Analyses presented here are for the British White and British Pakistani groups as numbers in other ethnic groups were too small (<75 infants in each group). Of the 1917 women eligible, 1735 consented but 28 were excluded as they had twin births, leaving 1707. Of them 1305 (76.5 %) completed the 6-month visit (age range at visit: 4.9–9.4 months), 1286 (75.4 %) the 12-month visit (age range at visit: 10.7–18.3 months), 1263 (74.0 %) the 18-month visit (age range at visit: 15.2–22.9 months), 1201 (70.4 %) the 24-month visit (age range at visit: 23.4–28.5 months) and 1232 (72.1 %) the 36-month visit (age range visit: 35.4–40.6 months).

Ethnicity classification followed the categories and nomenclature in the census for England and Wales 2001, including capitalisation of ethnic group categories, and utilised established concepts and principles [19,20]. The ethnicity of the children was based on mother's self-defined ethnicity in the baseline questionnaire.

The infants were visited at home or in clinics where further questionnaires were completed by the mother or other parent or guardian and measures including skinfolds were made [17]. Measurements of subscapular, triceps and thigh skinfolds were obtained by trained study administrators using Harpenden Calipers (Holtain Ltd) on the left side of the body. Data on skinfolds, sex and ethnicity were available for 1321 children with a median of four measurements per child for triceps (interquartile range (IQR) 3–5) and subscapular (IQR 3–5) and three for thigh (IQR 3–5).

2.1. Statistical analyses

Skinfold measurements comprised a nested measurement where, for analysis, level one is the skinfold measurements over time and level two is the infant. Such measures are autocorrelated and not independent, requiring multilevel modelling. We followed previously published methods to investigate skinfold trajectories between Pakistani and White British children in the Born in Bradford cohort [21]. Our models allowed for the change in the measurements over time and used all available data and a missing-at-random assumption. The proportion of missing values, under 10 % for the skinfolds, is shown in supplementary material appendix 1. The models allowed for individual variation in growth trajectories, with random effects allowing each individual to have different intercepts and slopes.

Fractional polynomial models determined the best fitting average, smooth growth patterns in skinfolds. This enabled modelling of the relationship between the outcome and continuous covariates. The continuous covariate, e.g. age, was raised to combinations of powers, creating multiple curves and increasing flexibility compared to standard polynomials [22,23]. Powers of −2, −1, −0.5, 0, 0.5, 1, 2, 3, were examined using the fp command in Stata (where a power of zero is the log function) within the multilevel framework and the best model determined for each of the three skinfolds. [24]. An example of the full model notation and example STATA code for models used can be found in the supplementary material (appendix 1).

We then created linear spline models within a multilevel model framework using the mkspline command in Stata for the splines and the mixed command for the multilevel models [24]. These models allow distinct slopes at different time periods to account for different growth velocities at different time periods. As no previous studies utilising these methods for skinfold trajectories were found, we calculated the best fitting time periods for knot point placement, firstly, by visual inspection of the models. Secondly, we created a range of models including (i) a linear model with no knot point, (ii) restricted cubic spline models, (iii) models with a single knot point at months 5–39 months and (iv) models with the placement of the first knot point at ages 5, 6, 7, 8, 9 and 10 months and then with all combinations of a second knot point at 7–39 months. Models were then compared and the model with the lowest corresponding Akaike's Information Criterion (AIC) selected as the best fitting, most parsimonious model. This same process was repeated separately for each skinfold site. These results of these analyses can be provided upon request.

We then created models for each of subscapular, triceps and thigh skinfold, firstly using spline terms only. Secondly, sex and ethnic differences in growth trajectories were examined by fitting interaction terms between ethnic and sex groups (four groups: White British and British Pakistani boys, White British and British Pakistani girls) with the parameters from these interactions indicating whether there were differences in starting skinfold measurements or growth in each time period. Finally, models were adjusted for additional potential confounding and/or mediating variables of maternal education, body mass index (BMI), gestational diabetes, parity, hypertension, smoking, and length of gestation; and child's birthweight and length.

Mean differences in growth per spline period between groups are shown as the British Pakistani group minus the White British (reference) group by sex, and presented with the corresponding 95 % confidence interval of the difference.

3. Results

The key results for this paper are summarised in adjusted trajectories in Figs. 1–3 and Table 1. Appendix 2 provides supplementary information as follows: Table S1 summarises the availability of skinfolds data, Table S2 the unadjusted ethnic differences of the measures at each of the measurement points (6, 12, 24 and 36 months), Table S3 the characteristics of the sample including variables used for adjustment, and S4-6 the unadjusted differences including both at the spline points and at the measurement times.

Data on one or more skinfolds were available for 1295 people with a minimum of 1179 participants (subscapular). Comparing the background characteristics of White British and Pakistani British mothers and/or British Pakistani boys and girls in this sub-cohort we observed in appendix 2, Table S2: higher birth weights, similar length, similar gestational weeks of pregnancy, lower parity, similar maternal hypertension, lower gestational diabetes, higher maternal smoking, more obesity, and complex differences in educational attainment. These patterns are similar to those reported in the larger Born in Bradford study [18,25]. Given such differences we prioritised adjusted findings.

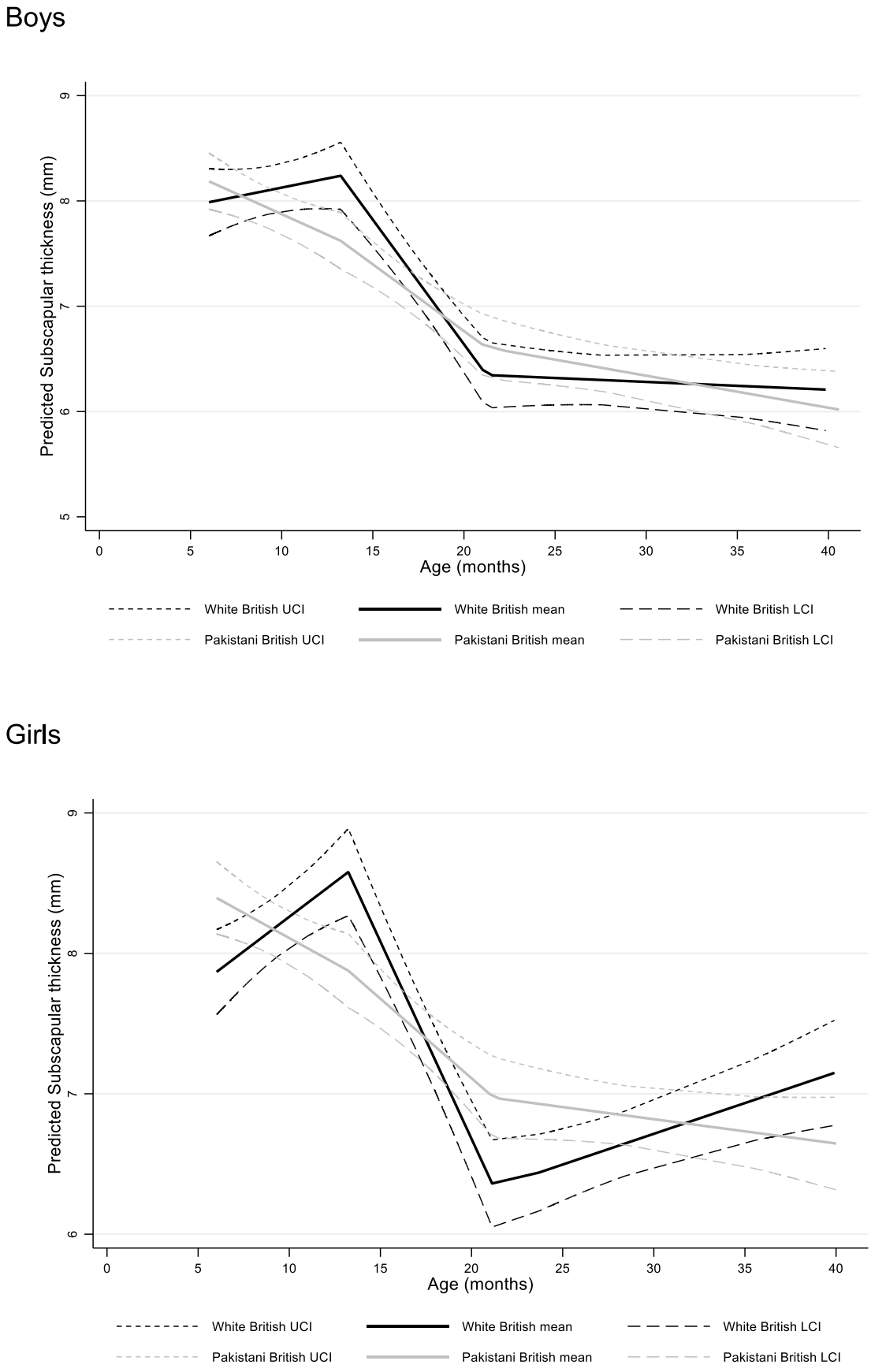

Fig. 1. Adjusted subscapular skinfold trajectory models for boys (above) and girls (below) UCI- Upper confidence interval, LCI- Lower confidence interval.

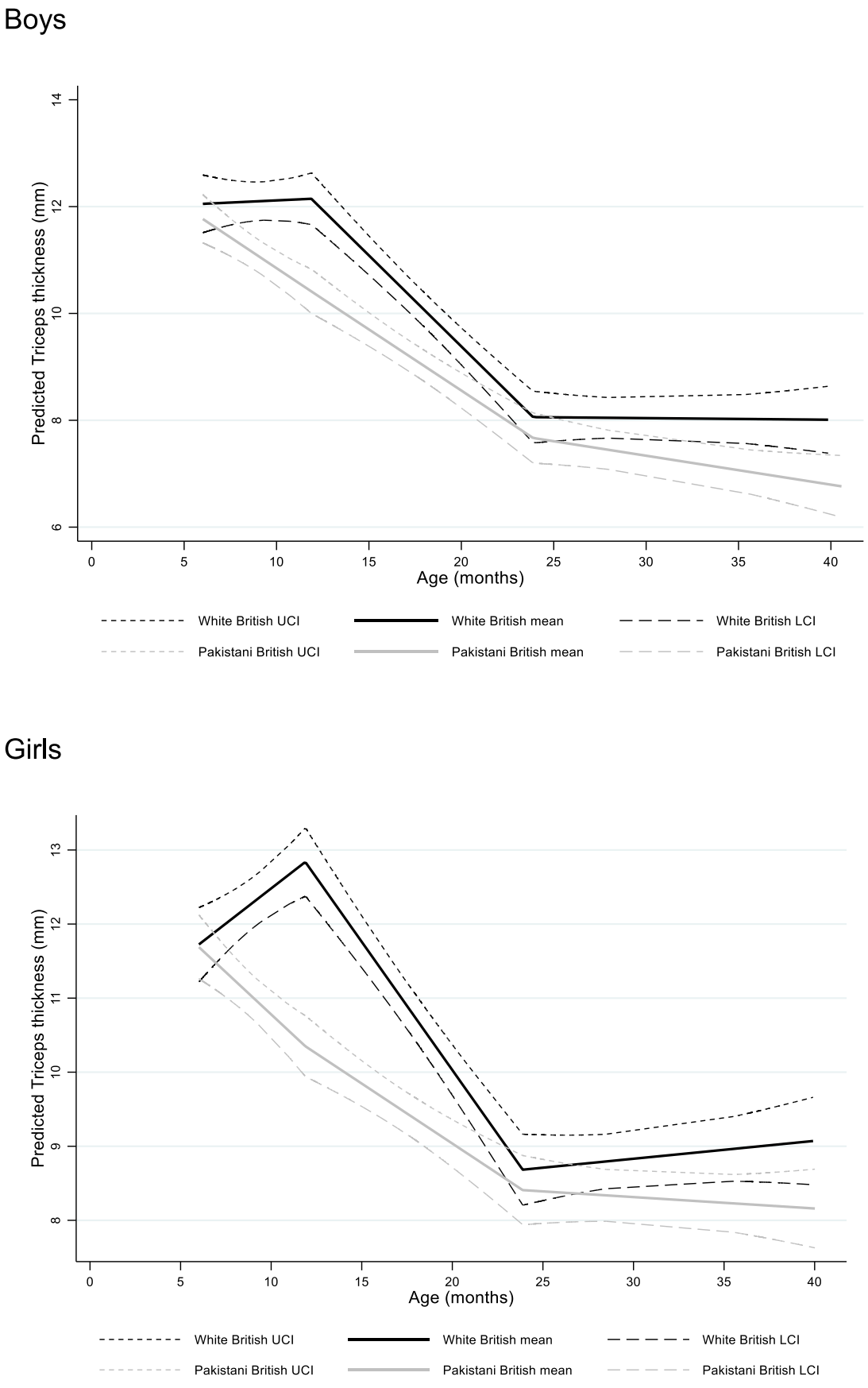

Fig. 2. Adjusted triceps skinfold trajectory models for boys (above) and girls (below) UCI- Upper confidence interval, LCI- Lower confidence interval.

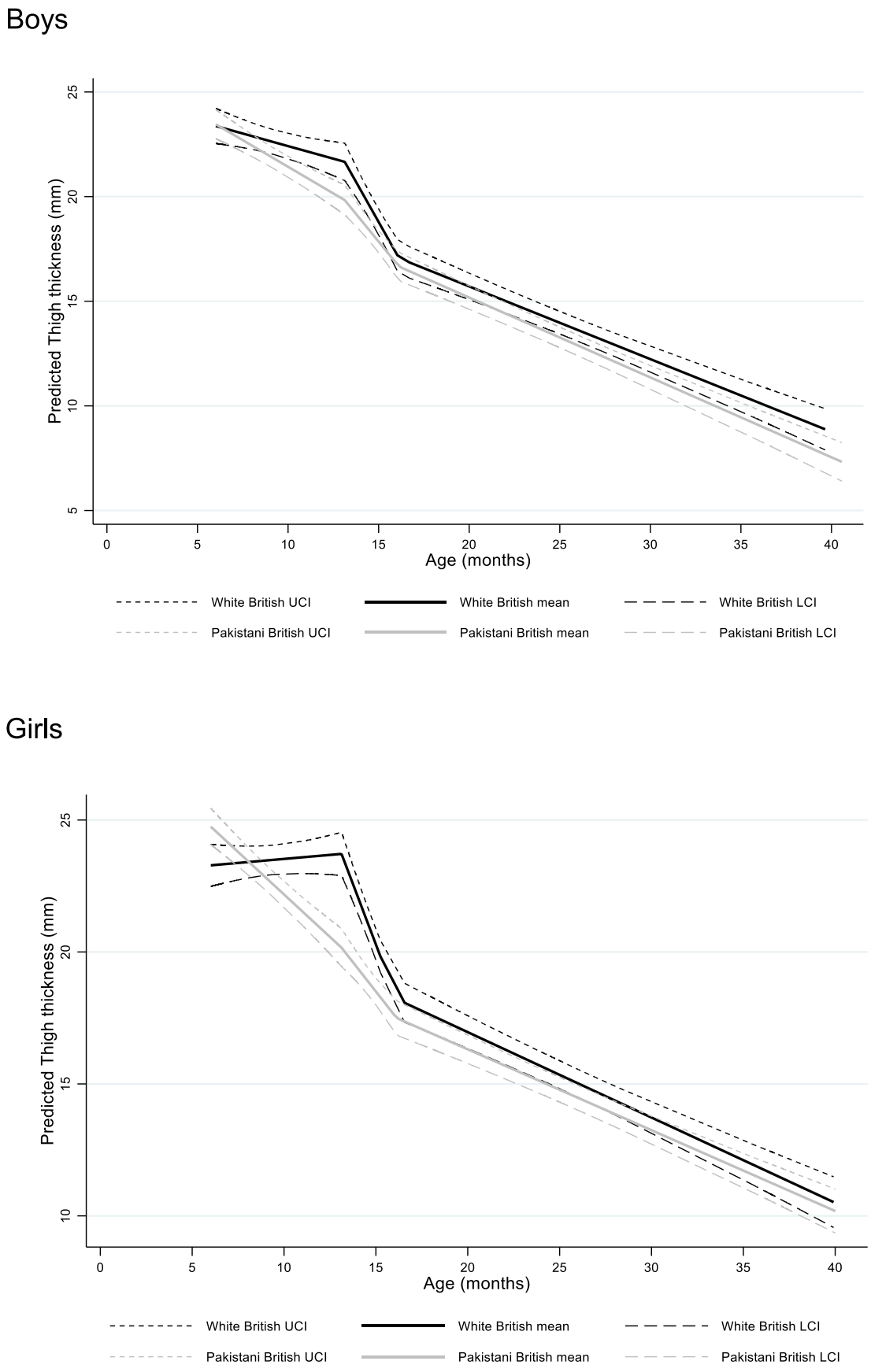

Fig. 3. Adjusted thigh skinfold trajectory models for boys (above) and girls (below) UCI- Upper confidence interval, LCI- Lower confidence interval.

Table 1
Adjusted differences by sex in skinfold thickness (mm) at 6-months and in growth rates (mm/month) by spline period, stratified by ethnic group (British Pakistani minus White British) and skinfold site.

		Adjusted for child's birthweight, length, smoking, maternal BMI, length of gestation, maternal education, gestational diabetes, parity and hypertension	
Time period (months)		Mean difference (mm)	95 % CI
Subscapular skinfolds			
Boys	6 months	0.97	0.18 to 1.77
Spline 1	6–13 months	0.06	−0.09 to 0.20
Spline 2	13–21 months	−0.37	−0.49 to −0.24
Spline 3	21–41 months	−0.03	−0.10 to 0.03
Girls	6 months	1.53	0.78 to 2.29
Spline 1	6–13 months	0.17	0.09 to 0.25
Spline 2	13–21 months	−0.18	−0.25 to −0.10
Spline 3	21–41 months	0.06	0.02 to 0.10
Triceps skinfolds			
Boys	6 months	−0.55	−0.69 to −0.41
Spline 1	6–11 months	0.22	−0.07 to 0.50
Spline 2	11–23 months	−0.43	−0.58 to −0.29
Spline 3	23–41 months	0.06	−0.06 to 0.18
Girls	6 months	−0.30	−0.45 to −0.15
Spline 1	6–11 months	0.40	0.25 to 0.56
Spline 2	11–23 months	−0.18	−0.26 to −0.10
Spline 3	23–41 months	0.04	−0.03 to 0.11
Thigh skinfolds			
Boys	6 months	−0.63	−0.92 to −0.35
Spline 1	6–13 months	0.24	−0.14 to 0.63
Spline 2	13–16 months	−1.86	−2.67 to −1.04
Spline 3	16–41	−0.23	−0.36 to −0.09
Girls	6 months	0.77	0.45 to 1.08
Spline 1	6–13 months	0.70	0.48 to 0.92
Spline 2	13–16 months	−0.95	−1.41 to −0.48
Spline 3	16–41 months	−0.01	−0.09 to 0.06

3.1. Knot points and skinfold thickness trajectories

The best fitting knot points, based on model AIC results, were found to be at 13 and 21 months for subscapular skinfolds, 11 and 23 months for triceps skinfolds, and 13 and 16 months for thigh skinfolds.

3.2. Subscapular skinfolds

Fig. 1 shows that White British (black lines) and British Pakistani children (red lines) had subscapular skinfold thicknesses with inconsistent variation over time and overlapping 95 % confidence intervals, and such inconsistency is confirmed in Table 1 (and, Supplementary Table S4 which provides analysis of the unadjusted differences both at the spline points and the measurement points).

Table 1 shows that adjusted growth rates in subscapular skinfold thickness varied at the spline points. In British Pakistani boys, growth was slower than in White British boys between 13 and 21 months, and similar at the other two spline periods between 6 and 13 months and 21 and 41 months. In British Pakistani girls, growth was faster than in White British girls at spline 1 between 6 and 13 months; spline 3 between 21 and 40 months; but slower at spline 2 between 13 and 21 months.

3.3. Triceps skinfolds

Fig. 2 shows that White British (black lines) and British Pakistani children (grey lines) had fairly consistent differences in triceps skinfold thicknesses despite sometimes overlapping 95 % confidence intervals, with the skinfolds in British Pakistani boys and girls mostly being lower throughout the study period (consistent with the adjusted results in Table 1 and Supplementary Table S5 which provides analysis of the unadjusted differences both at the spline points and the measurement points).

Table 1 shows that adjusted growth rates in triceps skinfold thickness in British Pakistani boys' growth were lower than in White British boys at spline 2, between 11 and 23 months and similar during the other 2 spline periods from 6 months to 11 and 23–40 months respectively. In British Pakistani girls, the growth rate was higher than in White British girls at spline 1 between 6 and 11 months; lower at spline 2 between 11 and 23 months; and near identical at spine 3 from 23 to 40 months.

3.4. Thigh skinfolds

Fig. 3 shows that British Pakistani children (grey lines) had adjusted mean thigh skinfold thicknesses mostly lower than in White British (black lines) with often overlapping 95 % confidence intervals (consistent with adjusted results in Table 1 and Supplementary Table S6 which provides analysis of unadjusted differences both at the spline points and the measurement points).

Table 1 shows that adjusted growth rates in triceps skinfold thickness in British Pakistani boys were lower than in White British boys at spline periods 2 and 3, growth between 13 and 16 and 16 and 40 months respectively, while higher at spline 1 growth between 6 and 13 months (95 % confidence interval included zero). In British Pakistani girls, growth was lower than in White British girls at spline 1 growth between 6 and 13 months, and lower at spline 2 between 13 and 16 months y, and near identical at spline 3, growth between 16 and 40 months.

4. Discussion

4.1. Principal findings

We found some differences between UK-born Pakistani and White British children in skinfold thickness and trajectories in early life. The skinfold differences were partially consistent with Sniderman et al.'s adipose tissue compartment hypothesis i.e., in British Pakistani compared with White British children we observed mostly, but not entirely consistently, smaller triceps and thigh skinfolds in boys and girls across the 3 year trajectory. While we observed similar, but not higher, subscapular skinfolds in boys and girls the pattern was consistent with a relative deficit of peripheral adipose tissue as predicted by Sniderman et al. and in line with recent reviews [14,15]. Overall, however, support in favour of the hypothesis was modest. We summarise the strengths and limitations of our study at the end of the discussion.

4.2. Findings in the context of the scientific literature

Differences in body composition internationally were established in the 19th century including Bergmann's Rule of 1847 that body mass index increases in cooler environments [26]. Allen's Rule of 1877 states that the exposed portions of the body including the limbs decrease in cooler environments [26]. Birthweight follows these rules i.e. higher in cold climates. Similarly, central skinfolds (subscapular) are thinner in cold climates, and triceps is thicker possibly also related to climate [26,27]. Wells proposed that the distribution of body fat is an evolutionary response to the pattern of infection e.g. gastrointestinal disorders, which he argues are particularly common in South Asia, lead to central deposition of fat [28]. In comparing South Asian and White European populations in both the scientific literature and in work within the Born in Bradford Cohort Study we have found some important conformity with rules about body composition and climate established in the 19th century including lower thresholds for healthy BMI, lower birthweight, and smaller peripheral skinfolds, particularly the triceps. We discuss this further below. Ethnic differences in birth weight and deposition of fat may, therefore, partially reflect evolutionary, genetic factors that would continue across generations.

Our work supports and adds to a recent systematic review on overweight/obesity in South Asian children in finding a complex picture [29]. Gulliford et al. reported higher subscapular skinfold thicknesses and lower triceps thicknesses in Indo Trinidadian children living in Trinidad and Tobago in 1990 compared with the 1990 British National Study of Health and Growth. They had no measures of lower limb skinfolds [30]. Our data on triceps aligns with theirs but those on subscapular skinfold thickness do not.

Sletner et al. in Norway, using maternal place of birth as an indicator of ethnicity of the baby and combining boys and girls found that thigh skinfolds at birth were slightly smaller in infants of mothers born in Pakistan, (N = 87; 5.4 mm) compared with infants of Western Europeans (N = 229; 6.0 mm), and Sri Lankan/Indian origin (N = 49; 6.0 mm) [7]. This pattern of smaller skinfolds in Pakistani babies was observed in subscapular, triceps and suprailiac skinfolds indicating thinness. The British Pakistani babies in Bradford were also lighter, longer and thereby thinner than White British ones. This aligns with Bergmann's rule [26]. Our study, by contrast to Sletner et al.'s, showed similar subscapular skinfold thickness and mostly, but not consistently, lower peripheral skinfolds in Pakistani babies across the three year trajectory, in line with Allen's rule [26]. A study in New York found differences in thigh skinfold thickness around birth by gender and ethnicity categorised as Caucasian, Hispanic, African American and Asian but the latter combined South and East Asian hindering direct comparisons with our study [31].

Thigh skinfold data have been studied rarely in South Asian adults. McKeigue et al. showed in a cross-sectional study that South Asian women had higher BMIs than European women and larger subscapular and suprailiac skinfolds, but similar thigh and suprapatellar skinfolds [4,32]. Our data, together with the literature cited above, suggest that the phenotype of small peripheral skinfolds relative to central skinfolds as described by McKeigue et al. in adult South Asians in London may evolve in early life [4,16,32].

We found no other comparable studies describing temporal skinfold trajectories. We observed that trajectories varied, albeit inconsistently over time and by sex, across ethnic groups. These observations require corroboration in larger studies.

4.3. Implications, conclusions and future research

Public health strategy to control the epidemic of cardiometabolic diseases in South Asians emphasises adiposity, including a re-setting of norms [33]. Central adiposity is a long-established contender as a key underlying causal factor for South Asians tendency to cardiometabolic disorders [1,4]. The idea that the problem in South Asians, as in other populations, may be as much a deficit of potentially protective peripheral adipose tissue, as one of excess detrimental central fat, is relatively new. [11]:115 The IDF has long-standing guidelines that in South Asian adult men the waist size should be $\leq$ 90 cm compared to 98 cm in White men (80 cm for all women) [34]. The Indian Society of Cardiologists has declared Indians are obese at a BMI of 25 kg/m^2 [35]. This reasoning has potential consequences for infants and children but a review concluded that action on children would be premature [36]. Previously, in the Born in Bradford Cohort Study we reported physical and biochemical (leptin) evidence for a relative high fat mass in babies at birth [10,11,37] Our current data suggesting ethnic differences, albeit limited and somewhat inconsistent, in the distribution of adipose tissue, add to the evidence. The evidence base needs strengthening before drawing policy conclusions for children.

In their review of obesity in South Asian children El Sayed et al. concluded that future studies should be longitudinal, disaggregate broad ethnic groups, and provide a variety of metrics [38]. Our work is in line with El Sayed et al.'s and Sniderman et al.'s recommendations [15]. Given the limited scientific literature cited above, and our findings on skinfold trajectories, we invite more attention to the changing distribution of body fat across the life course by ethnic group, and greater focus on peripheral fat with further evaluation of Sniderman et al. adipose tissue compartment hypothesis [13,15,39,40].

4.4. Strengths of the study

The key strength of the study is provision of scarce, comparative, longitudinal data on skinfolds in children. Few studies have reported on ethnic differences in skinfold thicknesses in children and, to our knowledge, none provided skinfolds across time. The thigh data were collected specifically to help test the hypothesis proposed by Sniderman et al. especially given evidence of lower limb adipose tissue being protective rather than harmful [12,13,15]. Although Sniderman et al.'s paper has been heavily cited and their hypothesis has captured attention, the literature reviewed above and our findings, indicate that national public health policy on this matter would be premature. This does not preclude individuals and their health advisers from continuing to emphasise body fat distribution as part of a health maintenance programme. Our analysis method shows patterns of growth expressed as trajectories, with some apparent differences between ethnic groups. These observations suggesting varying trajectories require further exploration. Other strengths include the population setting, the high response rates, a sample size larger than other studies and analysis methods that took account of missing data as well as the analysis of growth trajectories [17,21].

4.5. Limitations of the study

Weaknesses of our study include the lack of data on other skinfolds and data analysis starting at 6 months as the study was embedded in routine clinical practice and collecting thigh skinfold data at delivery was judged impractical [18]. Skinfold measurements have substantial inter- and intra-observer variation though the thigh skinfold is possibly the most reproducible [41]. We have no other anthropometric measures of body fat including separating superficial and deeper layers of subcutaneous fat or visceral fat [15]. Subscapular skinfold is our only measure of torsal/central fat.

We have used highest level of maternal education as a measure of socio-economic status within this study as, unlike other measures, it was well reported by study participants with similar completeness across ethnic groups. Previous research has demonstrated that educational attainment is strongly associated with health-related attitudes, beliefs, values and behaviours [42]. This measure was less prone to differences in missing data by ethnicity within the cohort compared to other measures such as household income or maternal employment status. We acknowledge that this measure does not reflect all aspects of socio-economic status.

Systematic bias whereby measurements were made differently in British White and Pakistani children is unlikely with no evidence of this across measures and sexes. Our measures stopped at 3-years, while ideally, they would be on a longer timescale. Some of the differences had considerable statistical uncertainty, and some were small in absolute terms. We did not combine the results from boys and girls because of sex differences in fat metabolism and storage. This analysis focused on ethnic differences rather than those by sex. We have observed some potentially interesting and important differences by sex which may deserve more detailed analysis and discussion in a future paper. Larger and more detailed studies will be required to examine interactions and dissect the potential causal roles of covariates in our models e.g. whether confounders or moderators. Our data were collected in 2011 and the patterns of obesity are likely to have changed since then and may have affected skinfold variations by ethnic group.

Ethical approval

Approval was granted by Bradford Research Ethics Committee (Ref 07/H1302/112).

What is known about this research topic?

In adulthood people of South Asian origin have greater central adiposity and a greater risk of developing metabolic disease than White populations.

What this study adds and future implications

This study found that some of these differences in adiposity begin in early childhood. Future studies are needed to both replicate these findings and explore longer term trends.

Novelty statement

This study is, to our knowledge, the largest prospective cohort study investigating the adipose tissue overflow hypothesis. It is the first to report changes in body skinfold distribution over time in the first three years of life, comparing a South Asian and a British White population. As such, it adds novel information on the development of variations in body fat distribution measured by skinfolds in childhood.

Clinical relevance

Health professionals advising on the prevention and control of cardiometabolic diseases, especially in South Asian populations, emphasise the importance of body fat distribution, particularly fat deposited within and around the abdomen. The adipose tissue compartment hypothesis provides an explanation of why South Asian populations particularly, but not uniquely, have relatively small quantities of peripheral fat and relatively higher quantities of central fat in comparison with European origin White populations. The hypothesis has proven of interest and is widely cited and discussed. This paper adds new information to a sparse research literature about whether patterns of central body fat distribution arise in childhood and if so, how they change within the first three years of life. The authors conclude that there is still insufficient evidence to justify public health policy but this new research supports clinicians advocating for the avoidance of central obesity from early childhood onwards.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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RB conceived the idea for the study, co-wrote and provided feedback on the manuscript, ESP performed all analyses and co-wrote the first draft of the manuscript, WJ, LS, TN and DAL provided feedback on both the statistical analyses and the manuscript, GC, NB, NC, JWest and JWright provided feedback on the manuscript. All authors edited and approved the final version of the manuscript.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dsx.2025.103227.

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