

Body size and body composition: a comparison of children in India and the UK through infancy and early childhood

S D'Angelo,¹ C S Yajnik,² K Kumaran,² C Joglekar,² H Lubree,² S R Crozier,¹ K M Godfrey,^{1,3} S M Robinson,¹ C H D Fall,¹ H M Inskip,¹ the SWS Study Group and the PMNS Study Group

¹MRC Lifecourse Epidemiology Unit, (University of Southampton), Southampton General Hospital, Southampton, UK

²Kamalnayan Bajaj Diabetes Research Unit, King Edward Memorial Hospital Research Centre, KEM Hospital, Pune, Maharashtra, India

³NIHR Southampton Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Foundation Trust, Southampton, UK

Correspondence to

Stefania D'Angelo, MRC Lifecourse Epidemiology Unit, (University of Southampton), Southampton General Hospital, Southampton SO16 6YD, UK; sd@mrc.soton.ac.uk

Received 25 September 2014

Revised 29 May 2015

Accepted 2 July 2015

ABSTRACT

Background Indian babies are characterised by the 'thin-fat phenotype' which comprises a 'muscle-thin but adipose' body composition compared with European babies. This body phenotype is of concern because it is associated with an increased risk of diabetes and cardiovascular disease. We examined whether the 'thin-fat phenotype' persists through early childhood, comparing Indian children with white Caucasians in the UK at birth, infancy and childhood, using comparable measurement protocols.

Methods We used data from two cohorts, the Pune Maternal Nutrition Study (N=631) and the Southampton Women's Survey (N=2643). Measurements of weight, head circumference, mid-upper arm circumference, height, triceps and subscapular skinfold thickness were compared at birth, 1, 2, 3 and 6 years of age. SD scores were generated for the Pune children, using the Southampton children as a reference. Generalised estimating equations were used to examine the changes in SD scores across the children's ages.

Results The Indian children were smaller at birth in all body measurements than the Southampton children and became relatively even smaller from birth to 2 years, before 'catching up' to some extent at 3 years, and more so by 6 years. The deficit for both skinfolds was markedly less than for other measurements at all ages; triceps skinfold showed the least difference between the two cohorts at birth, and subscapular skinfold at all ages after birth.

Conclusions The 'thin-fat phenotype' previously found in Indian newborns, remains through infancy and early childhood. Despite being shorter and lighter than UK children, Indian children are relatively adipose.

INTRODUCTION

Around 65 million people in India are currently affected by type 2 diabetes and the Indian Diabetes Federation predicts that this number will increase up to 109 million by 2035.¹ Additionally, Indians have a higher prevalence of the metabolic syndrome (central obesity, glucose intolerance, hyperinsulinaemia, hypertension, low plasma high-density lipoprotein cholesterol, and high triglycerides) compared with European populations.^{2–5}

Obesity is a major risk factor for insulin resistance, which induces diabetes. It has previously been shown that adults of Indian origin have a body phenotype that differs from those of European descent. Given a similar or even lower

body mass index (BMI), they have a higher percentage body fat and more central visceral fat.^{2 3 6 7}

The concept of the 'thin-fat phenotype' is now well established, and it characterises the body composition of Indian newborns. It has been described as a 'muscle-thin but adipose' body composition,⁸ because Indian babies are smaller in all anthropometric measurements considered, but with relative preservation of body fat.

Several studies have compared the body composition of children born in India with white Caucasian children in the UK. Yajnik *et al*^{9 10} compared the anthropometry of rural Indian babies from the Pune Maternal Nutrition Study (PMNS), and a separate sample of urban-born babies, with newborns in Southampton and London, respectively. Lakshmi *et al*¹¹ compared PMNS children at 6 years of age with children from the city of Plymouth, using dual X-ray absorptiometry. Krishnaveni *et al*¹² examined the anthropometry of urban South Indian children from the Mysore Parthenon Cohort as compared with UK white Caucasian children at three time points up to 4 years of age, but had to use different comparator populations at birth and during childhood. All these studies showed evidence of the 'thin-fat phenotype' in Indian children. However, the numbers in the comparator UK samples were small, and comparable anthropometry protocols were not always used in the two countries.

To our knowledge, there are no studies comparing Indian children with white Caucasians in the UK that (1) used comparable measurement protocols, (2) compared the two populations longitudinally, at birth and at four different ages in early childhood, and (3) had a large UK comparator group. Using data from the PMNS and the Southampton Women's Survey, we conducted such a comparison to examine whether the 'thin-fat phenotype' is present at birth, and through infancy and childhood up to 6 years.

METHODS

Data source

The Indian children came from the PMNS. Details of the study have been published elsewhere.^{13 14} In brief, between 1994 and 1996 all married women of reproductive age living in six villages near the city of Pune were recruited. Of 2675 married eligible women (aged 15–40 years), 2466 women (92%) agreed to participate. They were followed-up every

To cite: D'Angelo S, Yajnik CS, Kumaran K, *et al*. *J Epidemiol Community Health* Published Online First: [please include Day Month Year] doi:10.1136/jech-2014-204998

month to record their menstrual periods and every 3 months to measure their body composition. A total of 797 women who became pregnant were studied twice during pregnancy and the children have been followed-up annually with detailed anthropometry.

The UK comparator children were drawn from the Southampton Women's Survey. Full details of the study have been published elsewhere.¹⁵ Between 1998 and 2002, 12 583 women aged 20–34 years and resident in Southampton were interviewed and their diet, body composition, lifestyle, physical activity, hormone levels and social circumstances were recorded. A total of 3158 babies were subsequently born to women in the study and they have been followed-up through infancy and childhood.

This analysis is limited to singleton, live-born, full-term (gestational age ≥ 37 weeks) babies and in the Southampton study only white Caucasian babies were included, with ethnicity of the babies being defined according to the ethnicity of the mothers. Information on anthropometric measurements was available at birth, 1, 2 years and in subsamples of children, at 3 and 6 years.

Of the 3158 live singleton babies born in Southampton, two were excluded because limited obstetric information was available, 141 because they were not white Caucasians, 184 because they were preterm, 155 because they were born to women with hypertension, 24 born to women with gestational diabetes, 7 born with major anomalies and 2 because of missing anthropometry data. This left data on 2643 babies available for analysis.

Of the 762 live singleton babies born in Pune, 71 were excluded because they were preterm, 9 because of major anomalies and 51 did not have measurements made within 72 h of birth. Babies born to one woman with gestational diabetes and one with pregnancy-induced hypertension were excluded. Thus data on 631 babies were available for analysis.

Both cohort studies were conducted according to the guidelines laid down in the Declaration of Helsinki. The Pune study was approved by the King Edward Memorial Hospital Research Centre ethics committee and the SWS was approved by the Southampton and South West Hampshire Local Research Ethics Committee.

Measurements of the children

In the PMNS, the babies were measured within 3 days of birth, and in the SWS within 4 days. The anthropometric measurements in the two cohorts followed comparable protocols, and the staff in India and in the UK were trained in the same way. The measurements made at each age were: weight, head circumference, mid-upper arm circumference (MUAC), crown-heel length at birth and 1 year and height at the other time points and triceps and subscapular skinfold thickness.

In Southampton, crown-heel length was measured using a neonatometer (Harpenden, Wrexham, UK) at birth, and using an infantometer (Seca, Birmingham, UK) at 1 year. At the other ages, height was measured with a Leicester measurer. In Pune, a portable Pedobaby Babymeter (Pedobaby, ETS, JMB, Brussels, Belgium) was used at birth and at 1 year, while from 2 to 5 years standing height was measured to the nearest 0.1 cm using a portable Harpenden stadiometer, and at 6 years using a wall-mounted Microtoise (CMS Instruments Ltd, London, UK). In Pune, weight was measured to the nearest 0.1 kg using electronic weighing scales (ATCO Healthcare Ltd, Mumbai, India) and in Southampton using Seca scales. Holtain Calipers (CMS Instruments, London, UK) were used to measure skinfold

thickness in both studies. In Pune, head circumference and mid-upper arm circumference were measured to the nearest 0.1 cm with fibreglass tapes (CMS Instruments). In the SWS, head (maximum occipitofrontal circumference) and mid-upper arm circumference were measured three times using unmarked tapes, which were read off against a steel ruler.

In Southampton, gestational age at birth was calculated from the date of mother's last menstrual period (LMP) and confirmed by ultrasonography, or calculated following an early dating scan if mother had been uncertain about her LMP date. In Pune, gestational age was derived from the last menstrual period unless it differed from the sonographic estimate by more than 2 weeks, in which case the latter was used.

Statistical analyses

Measurements at birth were adjusted for gestational age and sex, while at the other time points they were adjusted for gestational age, sex and age. Southampton children were used as the comparator and SD scores for each Pune child were generated as follows:

$$\text{Pune SD score} = (\text{Pune observation} - \text{Southampton mean}) / \text{Southampton SD}$$

Subscapular skinfold thickness was log transformed to satisfy assumptions of normality and then SD scores were computed. The SD can be interpreted as the number of SDs a Pune observation is above/below the Southampton mean. It allows comparison between variables of different size and different units of measurements. Mean Pune SD scores (and 95% CI) for each measurement was presented using bar charts. Finally, generalised estimating equations (GEEs) were used to examine the changes in SD scores across the children's ages. The GEE approach allowed us to account for the correlation among repeated observations contributed by a single participant.¹⁶ The change in Pune SD scores across ages was assessed by comparing measurements at 1, 2, 3 and 6 years with those at birth (reference), with age considered as a categorical variable. A separate analysis considered age as a continuous variable to test for linear and quadratic effects. Results are shown with β coefficients and 95% CI. All the analyses were performed using Stata $\sqrt{13.1}$.

RESULTS

The anthropometric characteristics of the mothers and the children in both studies are summarised in [table 1](#).

Pune mothers tended to be younger at delivery, shorter and to have a lower pre-pregnancy weight than Southampton mothers. The median duration of breastfeeding for women in Southampton was 2 months while it was 5 months for women in India. Southampton mothers were on average 18 years old when they left full-time education, while women in Pune attended school on average for 6 years (data not shown). At all ages and for all measurements considered, the Pune children were on average smaller than the Southampton children, and this is also seen in [figures 1–6](#) which give the Pune SD scores across the ages for each of the six measurements.

Consistently across all postnatal ages, head circumference showed the greatest deficit for Pune children when compared with those in Southampton, though at birth the deficits were marginally greater for weight and mid-upper arm circumference ([figures 1–3](#)). The deficits for both skinfolds were markedly less than for other measurements at all ages; triceps skinfold showed the smallest difference between the two cohorts at birth, and subscapular skinfold at all ages after birth ([figures 4 and 5](#)).

Table 1 Characteristics of the mothers and children included in the analyses at birth, 1, 2, 3 and 6 years

	Pune			SWS		
	N	mean	SD	N	mean	SD
Maternal characteristics						
Age at delivery (y)	631	21.44	3.57	2643	30.70	3.85
Height (m)	631	1.52	0.05	2630	1.63	0.06
Pre-pregnancy weight (kg)	631	41.1*	(38.0–45.0)	2623	64.5*	(58.2–72.7)
Breastfeeding duration (m)	469	5.0*	(3.0–6.0)	2425	2.0*	(0–6.0)
Head circumference (cm)						
Birth	627	33.25	1.08	2489	34.91	1.13
1 year	583	44.20	1.30	2352	46.96	1.29
2 years	585	46.12	1.28	2172	49.25	1.35
3 years	605	47.70	1.25	1313	50.41	1.54
6 years	590	50.20	1.59	769	52.30	1.61
Crown-heel length/height (cm)						
Birth	626	48.02	1.82	2461	49.73	1.66
1 year	583	72.94	2.80	2275	76.19	2.50
2 years	583	82.64	3.35	2156	86.84	3.01
3 years	604	90.30	3.47	1305	95.95	3.92
6 years	590	114.68	4.73	770	119.22	5.36
Weight (kg)						
Birth	631	2.73	0.34	2599	3.44	0.43
1 year	583	8.17	0.94	2354	10.22	1.10
2 years	582	10.04	1.12	2234	12.76	1.45
3 years	600	12.42	1.20	1318	15.12	1.99
6 years	590	19.24	2.39	771	22.91	3.82
Mid-upper arm circumference (cm)						
Birth	627	9.80	0.85	2488	11.38	0.87
1 year	582	13.99	1.06	2363	15.93	1.17
2 years	585	14.25	1.02	2182	16.31	1.20
3 years	604	14.92	1.12	1292	16.96	1.41
6 years	590	16.68	1.33	768	18.53	1.89
Triceps skinfold (mm)						
Birth	627	4.25	0.84	2481	4.64	0.91
1 year	582	7.25	1.64	2263	10.89	2.40
2 years	584	7.66	1.81	1986	10.17	2.17
3 years	604	8.61	1.71	1241	10.24	2.32
6 years	590	7.99	1.78	737	10.38	3.28
Subscapular skinfold* (mm)						
Birth	627	4.16	3.64–4.69	2481	4.84	4.25–5.57
1 year	582	5.67	4.93–6.53	2294	6.96	6.01–8.14
2 years	585	5.44	4.82–6.26	1978	6.21	5.47–7.33
3 years	604	5.99	5.28–6.87	1222	6.20	5.45–7.32
6 years	590	5.65	5.00–6.35	735	5.80	4.98–6.94

*Median (IQR).

SWS, Southampton Women's Survey.

These findings indicate that in Indian children, fat is better preserved relative to other body compartments.

The difference in head circumference, weight and height between the Pune children and Southampton children increased from birth to age 2 years and decreased again by age 6 years (figures 1, 2, 6). Similar patterns were seen for the two skinfolds, though the deficits were greatest at age 1 year for these measurements (figures 4 and 5). For mid-upper arm circumference, the differences between the two cohorts reduced with age (figure 3).

Table 2 presents the results of the GEE analysis in which we evaluated the difference between Pune and Southampton children (in terms of Pune SD scores) between each age and birth.

For mid-upper arm circumference, the differences between Pune and Southampton reduced as the children became older. For all other measurements, the deficit in Pune children at birth amplified during infancy and early childhood, but reduced as the children became older. In further models (results not shown) in which age was considered as a continuous variable, the quadratic effect of age was highly significant ($p < 0.001$) for all body measurements. The coefficient for the quadratic term was positive for all body measurements with the exception of subscapular skinfold thickness. The modelled differences between SWS and Pune were largest at birth for weight, mid-upper arm circumference and subscapular skinfold thickness, and around 2–3 years for head circumference, height and triceps.

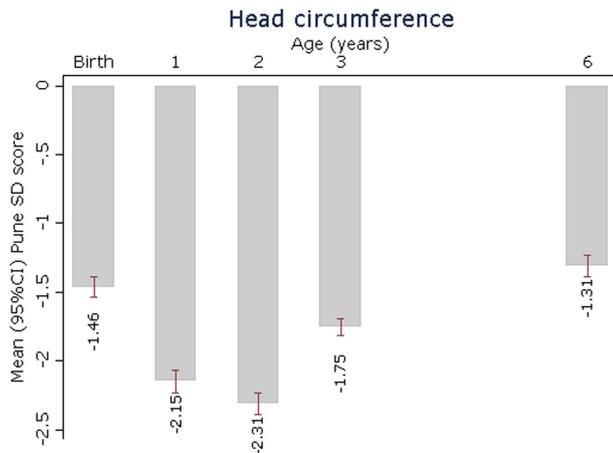


Figure 1 Pune SD scores of head circumference versus Southampton children at birth, 1, 2, 3 and 6 years.

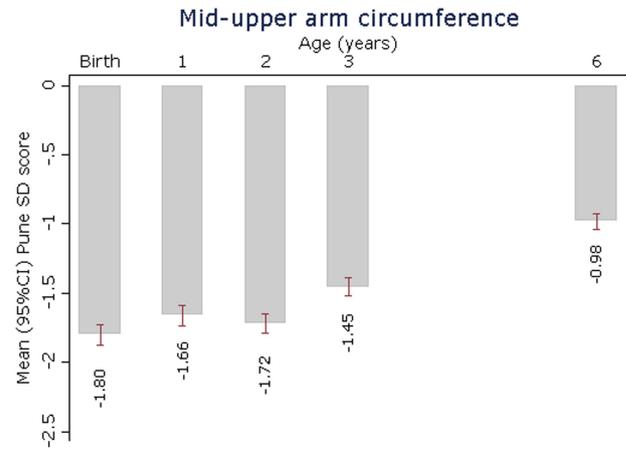


Figure 3 Pune SD scores of mid-upper arm circumference versus Southampton children at birth, 1, 2, 3 and 6 years.

DISCUSSION

Main findings

This study demonstrates that the Indian ‘thin-fat phenotype’ at birth persists through infancy and childhood up to 6 years. Despite being shorter and lighter than Southampton white Caucasian newborns, the Pune babies showed a relative preservation of body fat, assessed by subscapular and triceps skinfold thickness. Subscapular skinfold, a marker of ‘central’ adiposity, was the most preserved measurement at all ages postnatally. Mid-upper arm circumference showed a large deficit in the Indian babies, indicating that in addition to having more subcutaneous fat, they also show evidence of lower muscle mass.

The availability of longitudinal data in both populations allowed us to examine for the first time how the body composition of the Pune children relative to the Southampton children changed over the course of infancy and early childhood. We found that the Pune children, who were smaller at birth in all body measurements than the Southampton children, became relatively even smaller from birth to 2 years (especially for head circumference and triceps skinfold), before ‘catching up’ to some extent at 3 years, and showing further catch up by 6 years. A similar pattern was observed in all body measurements, with the possible exception of mid-upper arm circumference which showed the greatest relative deficit at birth, with the deficit changing little over the first three postnatal years but showing

some catch up by 6 years. We are not able to explain these changes, but growth faltering during the first 1–2 postnatal years is well described among children in undernourished populations, and is probably multifactorial and due to nutritional deficits (inadequate breastfeeding and poor quality complementary foods) and infections.¹⁷ Despite this, the relative sparing of adipose tissue, with subscapular skinfold showing less deficit relative to the Southampton children than any other measurements, was a strikingly persistent feature from birth to 6 years.

Comparison with other studies

It is well known that Indian babies tend to be born small,¹⁸ and it has been shown that this deficit is apparent even for Indians born in the UK;^{19 20} our study is consistent with these findings. Our comparison of detailed anthropometry between Indian and UK white Caucasian newborns and children was consistent with earlier comparisons made by Yajnik *et al*^{9 10} and Krishnaveni *et al*,¹² in showing that Indian babies and children are disproportionately adipose compared with white Caucasian babies and children. Lakshmi *et al*¹¹ showed a higher percentage body fat in the Pune children at age 6 years than in white UK children of the same age assessed using dual X-ray anthropometry. Our findings are also similar to those of multiethnic studies carried out in the UK. The ‘Born-in-Bradford’ study compared neonatal

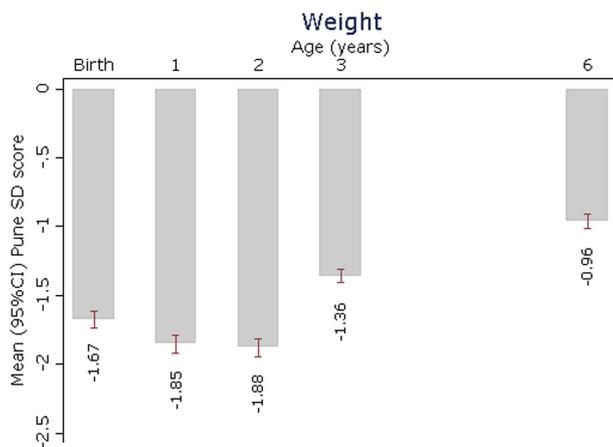


Figure 2 Pune SD scores of weight versus Southampton children at birth, 1, 2, 3 and 6 years.

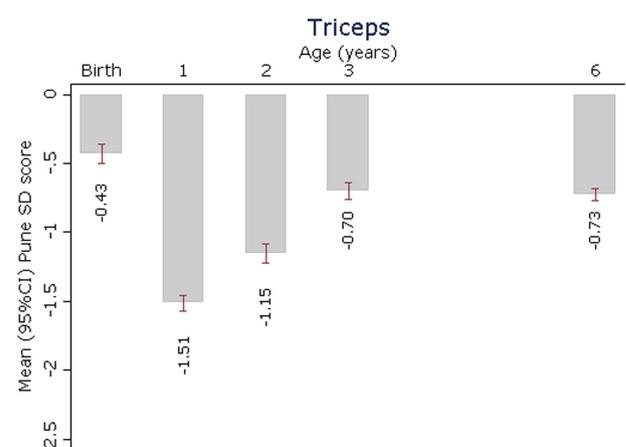


Figure 4 Pune SD scores of triceps skinfold thickness versus Southampton children at birth, 1, 2, 3 and 6 years.

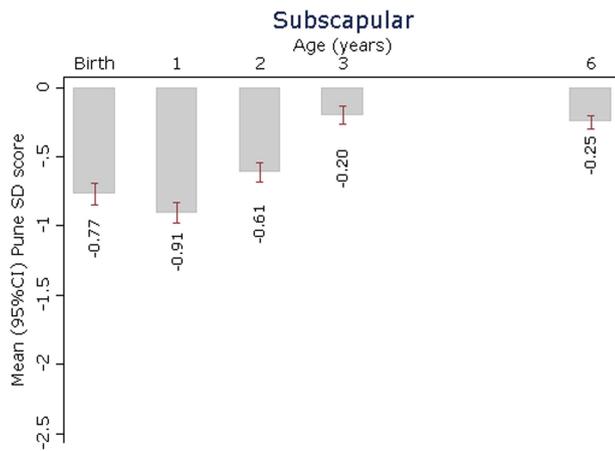


Figure 5 Pune SD scores of subscapular skinfold thickness versus Southampton children at birth, 1, 2, 3 and 6 years.

skinfold thickness and cord blood leptin concentrations between babies of Pakistani and white British origin born in the same UK maternity unit.²¹ It found that, despite being lighter, infants of Pakistani origin had similar skinfold thickness and higher leptin concentrations, suggesting a greater total fat mass than that in white infants. The ‘London Mother and Baby study’ showed that UK-born babies of South Asian origin had greater relative adiposity and a lower mean fat-free mass than white European babies, measured using air-displacement plethysmography (PeaPod).²² Modi *et al*²³ used MRI to measure total and regional adipose tissue content in a small sample of Indian (Pune) and white European newborns in the UK. They found that Indian babies had less total body fat in absolute terms than white Caucasian babies, but had significantly more abdominal adipose tissue. This was true for all three abdominal fat compartments (visceral, deep subcutaneous and superficial subcutaneous). Lastly, similar findings were noted at a later age (9–10 years old) by Nightingale *et al*²⁴ in the CHASE study, a survey in three British primary schools, which showed that children of South Asian origin had greater skinfold thickness and higher percentage body fat, measured using bio-impedance, than white Europeans.

Several evolutionary advantages have been suggested for the ‘thin-fat phenotype’. Greater newborn adiposity may be an

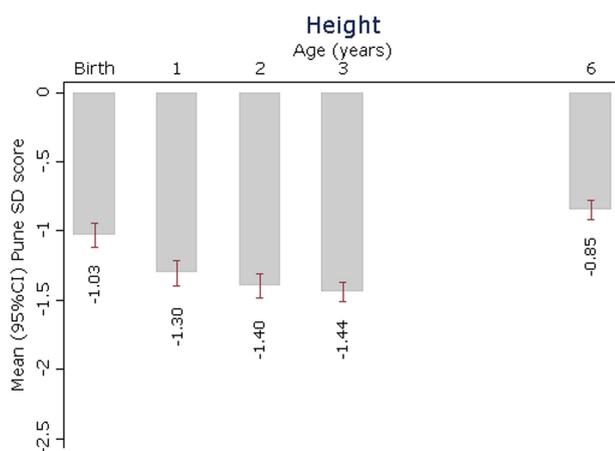


Figure 6 Pune SD scores of height versus Southampton children at birth, 1, 2, 3 and 6 years.

Table 2 Results of generalised estimating equation modelling of the relationship between Pune SD score and age

Age (years)	Head circumference β (95% CI)	Crown-heel length/height β (95% CI)	Weight β (95% CI)	Mid-upper arm circumference β (95% CI)	Triceps skinfold β (95% CI)	Subscapular skinfold β (95% CI)
Birth	Reference	Reference	Reference	Reference	Reference	Reference
1 year	-0.67 (-0.74 to -0.61)	-0.27 (-0.34 to -0.19)	-0.18 (-0.23 to -0.12)	0.14 (0.07 to 0.22)	-1.08 (-1.16 to -1.01)	-0.14 (-0.22 to -0.06)
2 years	-0.85 (-0.91 to -0.78)	-0.37 (-0.44 to -0.29)	-0.21 (-0.26 to -0.15)	0.08 (0.01 to 0.16)	-0.72 (-0.80 to -0.65)	0.16 (0.08 to 0.24)
3 years	-0.29 (-0.36 to -0.23)	-0.41 (-0.48 to -0.34)	0.31 (0.26 to 0.37)	0.34 (0.27 to 0.41)	-0.28 (-0.35 to -0.20)	0.56 (0.48 to 0.64)
6 years	0.15 (0.09 to 0.21)	0.17 (0.10 to 0.24)	0.70 (0.65 to 0.76)	0.81 (0.74 to 0.88)	-0.30 (-0.38 to -0.23)	0.51 (0.43 to 0.59)

Results show differences between Pune SD score at each age compared with the value at birth.

adaptation to enhance immediate neonatal survival; fat has advantages for small babies at birth by acting as an energy reserve and helping to maintain body temperature. It may act as a valuable substrate for postnatal brain development. An enhanced tendency to store fat may be a manifestation of a 'thrifty metabolism'; such 'thriftness', which could result from genes or programming by the intrauterine environment, could have been advantageous in the past, by aiding survival during acute food shortages and famines.²⁵ The large deficit in MUAC in the Pune newborns may signify inadequate substrate to grow muscle tissue in utero. The Pune mothers had low protein intakes and iron status during pregnancy. In children, dietary protein requirements as a percentage of energy are higher for growth of lean tissue compared with growth of adipose tissue.²⁶ Alternatively, or additionally, we speculate that the disproportionately small MUAC may indicate a fetal adaptation to 'sacrifice' the growth of muscle (a relatively unimportant tissue in utero) in order to prioritise the growth of other tissues (such as the brain). Muscle development becomes increasingly important postnatally, when its growth may become of higher priority (possibly explaining the steady catch-up in MUAC at every age postnatally, in contrast to the other tissues). Whatever the mechanism, the persistence of a relatively high-body fat and low lean body mass is likely to increase insulin resistance and the risk of later diabetes.

Strengths and limitations

This is a large study that compares Indian with UK white Caucasian children in terms of anthropometric measurements at birth, during infancy and early childhood, using two population-based cohorts. To our knowledge, this is the first study that was able to follow children from both countries over such a length of time, using comparable standardised protocols in both places at all-time points. Thus far, data in the SWS are only available for children up to 6 years and further study will be needed to investigate if the 'thin-fat phenotype' of Indians persists later in childhood, adolescence and adulthood. Furthermore, although we have measures of subcutaneous body fat, measures of whole body fat would give a more complete picture. The SWS provides data from a large contemporary cohort of women and their offspring from a wide range of sociodemographic backgrounds, and the full cohort is considered representative of the general population.¹⁵ The data at ages 3 and 6 years are from subsamples of study population; due to the wide range of dates of birth of the cohort, the data take time to accrue, and at age 6 years only a subsample from the cohort was targeted. The Pune cohort provides data from an undernourished population in India, who have not experienced the nutrition transition and exposure to high fat, sugar and processed foods. The findings, therefore, are not a reflection of exposure to a Western diet among these Indians, but represent an underlying difference between the two populations from before birth. The findings inform our understanding of differences that occur between populations and point towards factors operating antenatally.

Interpretations and implications

We have shown for the first time that compared with white Caucasian children, there is a tendency for the deficits in body measurements in Indian children to increase during infancy and early childhood before catching up by the age of 6 years. We have also shown that the 'thin-fat phenotype' is a consistent finding in Indian children up to 6 years old and that the propensity of adult Indians to have a higher percentage body fat than

European populations is established before birth and tracks through early childhood. This pattern of body composition among Indians is associated with increased risks of diabetes and cardiovascular disease later in life.

Our study suggests that there may be a case for exploring the value of carefully planned interventions to improve the growth of infants and children in populations similar to the Pune cohort.

What is already known on this subject?

- ▶ The 'thin-fat phenotype' describes the characteristic body composition of Indian newborns: they are smaller than Caucasian newborns, but with relative preservation of body fat.
- ▶ This body phenotype has been associated with higher risk of diabetes and cardiovascular disease.
- ▶ There is a lack of studies comparing Indian and Caucasian children at older ages, throughout infancy and childhood.

What this study adds?

- ▶ The 'thin-fat phenotype' of Indians persists from birth serially through infancy and childhood.
- ▶ Our findings suggest an intrauterine programming of body composition and risk of diabetes in Indians.
- ▶ Indian babies are smaller on average for all body measurements at birth, then become relatively even smaller during the first 2 years of life, but the deficits diminish as the children become older.

Acknowledgements The work within the Southampton Women's Survey was funded by the Medical Research Council, University of Southampton, British Heart Foundation, Foods Standards Agency (contracts N05049 and N05071), and the National Institute for Health Research through the NIHR Southampton Biomedical Research Centre; the research leading to these results also received funding from the European Union's Seventh Framework Programme (FP7/2007-2013), project EarlyNutrition under grant agreement n°289346. The work in Pune was funded by the Wellcome Trust, Medical Research Council and Department for International Development, UK. The authors are grateful to the mothers and children who participated in the studies and to the staff at both sites who collected and processed the data.

Contributors HMI, KMG, SMR and SRC designed and coordinated all aspects of the SWS survey. CHDF, CSY, KK, CJ and HL designed and coordinated all aspects of the PMNS survey. SD and HMI drafted the paper. SD performed the statistical analyses. All authors contributed to the interpretation of the data, the preparation of the manuscript, and approved its final version.

Competing interests None declared.

Patient consent Obtained.

Ethics approval The Pune study was approved by the King Edward Memorial Hospital Research Centre ethics committee and the SWS was approved by the Southampton and South West Hampshire Research Ethics Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

- 1 International Diabetes Federation. *IDF diabetes atlas Brussels*. Belgium: International Diabetes Federation, 2013. [23 Sep 2014]. <http://www.idf.org/diabetesatlas>
- 2 McKeigue P, Shah B, Marmot M. Relation of central obesity and insulin resistance with high diabetes prevalence and cardiovascular risk in South Asians. *Lancet* 1991;337:382–6.
- 3 Jaynik CS. The insulin resistance epidemic in India: fetal origins, later lifestyle, or both? *Nutr Rev* 2001;1:1–9.

- 4 Pandit K, Goswami S, Ghosh S, *et al.* Metabolic syndrome in South Asians. *Indian J Endocrinol Metab* 2012;16:44–55.
- 5 Misra A, Vikram NK. Insulin resistance syndrome (metabolic syndrome) and obesity in Asian Indians: evidence and implications. *Nutrition* 2004;20:482–91.
- 6 Yajnik C, Yudkin J. The Y-Y paradox. *Lancet* 2004;363:163.
- 7 Chandalia M, Lin P, Seenivasan T, *et al.* Insulin resistance and body fat distribution in South Asian men compared to Caucasian men. *PLoS ONE* 2007;2:e812.
- 8 Van Steijn L, Karamali NS, Kanhai HH, *et al.* Neonatal anthropometry: thin-fat phenotype in fourth to fifth generation South Asian neonates in Surinam. *Int J Obes (Lond)* 2009;33:1326–9.
- 9 Yajnik C, Fall C, Coyaji K, *et al.* Neonatal anthropometry: the thin-fat Indian baby. The Pune Maternal Nutrition Study. *Int J Obesity* 2003;27:173–80.
- 10 Yajnik CS, Lubree HG, Rege SS, *et al.* Adiposity and hyperinsulinemia in Indians are present at birth. *J Clin Endocrinol Metab* 2002;87:5575–80.
- 11 Lakshmi S, Metcalf B, Joglekar C, *et al.* Differences in body composition and metabolic status between white U.K. and Asian Indian children (EarlyBird 24 and the Pune Maternal Nutrition Study). *Pediatr Obes* 2012;7:347–54.
- 12 Krishnaveni GV, Hill J, Veena SR, *et al.* Truncal adiposity is present at birth and in early childhood in South Indian children. *Indian Pediatr* 2005;42:527–38.
- 13 Rao S, Yajnik CS, Kanade A, *et al.* Intake of micronutrient-rich foods in rural Indian mothers is associated with the size of their babies at birth: Pune Maternal Nutrition Study. *J Nutr* 2001;131:1217–24.
- 14 Kinare AS, Natekar AS, Chinchwadkar MC, *et al.* Low midpregnancy placental volume in rural Indian women: a cause for low birth weight? *Am J Obstet Gynecol* 2000;182:443–8.
- 15 Inskip HM, Godfrey KM, Robinson SM, *et al.* Cohort profile: the Southampton Women's Survey. *Int J Epidemiol* 2006;35:42–8.
- 16 Hanley JA, Negassa A, Edwardes MD, *et al.* Statistical analysis of correlated data using generalized estimating equations: an orientation. *Am J Epidemiol* 2003;157:364–75.
- 17 Black RE, Victora CG, Walker SP, *et al.* Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* 2013;382:427–51.
- 18 Muthayya S, Dwarkanath P, Thomas T, *et al.* Anthropometry and body composition of south Indian babies at birth. *Public Health Nutr* 2007;9:896–903.
- 19 Leon DA, Moser KA. Low birth weight persists in South Asian babies born in England and Wales regardless of maternal country of birth. Slow pace of acculturation, physiological constraint or both? Analysis of routine data. *J Epidemiol Community Health* 2012;66:544–51.
- 20 Margetts BM, Mohd Yusof S, Al Dallal Z, *et al.* Persistence of lower birth weight in second generation South Asian babies born in the United Kingdom. *J Epidemiol Community Health* 2002;56:684–7.
- 21 West J, Lawlor DA, Fairley L, *et al.* UK-born Pakistani-origin infants are relatively more adipose than white British infants: findings from 8704 mother-offspring pairs in the Born-in-Bradford prospective birth cohort. *J Epidemiol Community Health* 2013;67:544–51.
- 22 Stanfield KM, Wells JC, Fewtrell MS, *et al.* Differences in body composition between infants of South Asian and European ancestry: the London Mother and Baby Study. *Int J Epidemiol* 2012;41:1409–18.
- 23 Modi N, Thomas EL, Uthaya SN, *et al.* Whole body magnetic resonance imaging of healthy newborn infants demonstrates increased central adiposity in Asian Indians. *Pediatr Res* 2009;65:584–7.
- 24 Nightingale CM, Rudnicka AR, Owen CG, *et al.* 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). *Int J Epidemiol* 2011;40:33–44.
- 25 Yajnik CS. Nutrition, growth, and body size in relation to insulin resistance and type 2 diabetes. *Curr Diab Rep* 2003;3:108–14.
- 26 Jackson AA. Chronic malnutrition: protein metabolism. *Proc Nutr Soc* 1993;52:1–10.