Acta Obstetricia et Gynecologica. 2006; 85: 1066–1079

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Geographical variation in relationships between parental body size and offspring phenotype at birth

SAM LEARY[1,2], CAROLINE FALL[1], CLIVE OSMOND[1], HERMIONE LOVEL[3], DORIS CAMPBELL[4], JOHAN ERIKSSON[5], TERRENCE FORRESTER[6], KEITH GODFREY[1], JACQUI HILL[7], MI JIE[8], CATHERINE LAW[9], RACHEL NEWBY[10], SIAN ROBINSON[1] & CHITTARANJAN YAJNIK[11]

[1]*Medical Research Council Environmental Epidemiology Unit, University of Southampton, Southampton,* [2]*Avon Longitudinal Study of Parents and Children, University of Bristol, Bristol,* [3]*Work conducted at WHO Collaborating Centre for Primary Care, The University of Manchester, UK. Now East of England Public Health Group, Cambridge,* [4]*Department of Obstetrics and Gynaecology, University of Aberdeen, Aberdeen, UK,* [5]*Diabetes and Genetic Epidemiology Unit, National Public Health Institute, Helsinki, Finland,* [6]*Tropical Metabolism Research Unit, University of the West Indies, Kingston, Jamaica,* [7]*Holdsworth Memorial Hospital, Mysore, India,* [8]*Department of Epidemiology, Peking Union Medical College, Chinese Academy of Medical Sciences, China,* [9]*Centre for Paediatric Epidemiology and Biostatistics, Institute of Child Health, London, UK,* [10]*c/o Obstetrics and Gynaecology, University of Lubumbashi, Democratic Republic of Congo,* [11]*Diabetes Unit, King Edward Memorial Hospital, Pune, India*

Abstract

Background. Size and body proportions at birth are partly determined by maternal body composition, but most studies of mother–baby relationships have only considered the effects of maternal height and weight on offspring birth weight, and few have examined the size of effects. Paternal size and body composition also play a role, primarily through the fetal genome, although few studies have investigated relationships with neonatal phenotype. *Methods*. Data from the UK, Finland, India, Sri Lanka, China, DR Congo, Nigeria and Jamaica were used to investigate the effects of maternal measures (derived at 30 weeks' gestation, $n = 16{,}418$), and also paternal size ($n = 3{,}733$) on neonatal phenotype, for singleton, live-born, term births. *Results*. After accounting for variation in maternal size and shape across populations, differences in neonatal phenotype were markedly reduced. Mother–baby relationships were similar across populations, although some were stronger in developing countries. Maternal height was generally the strongest predictor of neonatal length, maternal head circumference of neonatal head and maternal skinfold thickness of neonatal skinfolds. Relationships with maternal arm muscle area were generally weak. Effects of paternal height and body mass index were weaker than the equivalent maternal measurements in most studies. *Conclusions*. Differences in maternal body composition account for a large part of the geographical variation in neonatal phenotype. The size of the effects of all maternal measures on neonatal phenotype suggests that nutrition at every stage of the mother's life cycle may influence fetal growth. Further research is needed into father–baby relationships and the genetic mechanisms that influence fetal growth.

Key words: *Size at birth, maternal body composition, maternal birth weight, paternal size, worldwide variation*

Abbreviations: *AMA: arm muscle area, BMI: body mass index, CH length: crown–heel length, CR length: crown–rump length, IQR: interquartile range, MUAC: mid–upper-arm circumference, DXA: dual X-ray absorptiometry*

Small body size and disproportion at birth is associated with increased morbidity in infancy and childhood, and susceptibility to coronary heart disease and associated disorders in later life (1). There are variations in neonatal phenotype around the world (see accompanying paper), and it is

Correspondence: Sam Leary, Avon Longitudinal Study of Parents and Children, University of Bristol, 24 Tyndall Avenue, Bristol BS8 1TQ, UK. E-mail: s.d.leary@bristol.ac.uk

(Received 5 December 2005; accepted 6 March 2006)

ISSN 0001-6349 print/ISSN 1600-0412 online
DOI: 10.1080/00016340600697306

important to understand their determinants in order to develop strategies to optimize fetal growth. Maternal size and body composition influence neonatal phenotype (2), but most studies have only considered maternal height and weight, and their effects on offspring birth weight.

Mother–baby relationships may be a result of environmental factors, epigenetic influences, inherited genes, and interactions between these. In contrast, father–baby relationships that are independent of maternal phenotype are likely to have a genetic basis. Some studies have assessed effects of paternal height and weight on offspring birth weight (3), but few have examined other birth measurements, or compared maternal and paternal influences.

Data from 18 studies around the world have been used (a) to assess the extent to which maternal size accounts for geographical differences in neonatal phenotype, in order to test the hypothesis that variations in maternal size account for a large proportion of these differences, (b) to compare the effects of different components of maternal body composition on neonatal phenotype across and within populations, to test the hypothesis that specific components of maternal body composition relate consistently to specific components of neonatal body composition, and (c) to compare maternal and paternal effects on neonatal phenotype, to test the hypothesis that there are significant genetic effects on size at birth.

Materials and methods

Studies

As many of the studies as possible from the accompanying paper were used for this analysis. These included the UK (Southampton (4–7), Farnborough (8), Isle of Man (9), Aberdeen (10)), Finland (Helsinki (11)), India (Mysore (12,13), Pune (14,15)), Sri Lanka (Kandy (16)), China (Beijing (17)), DR Congo (Kasaji (18)), Nigeria (Imesi (19)), and Jamaica (Kingston (20,21)). Two studies (Preston and Sheffield) were excluded because only maternal pelvic dimensions were recorded.

The setting, years of birth, and numbers used for this analysis for each of the studies are shown in Table I. Shaded rows refer to prospective studies (mothers recruited at or before delivery and babies measured as part of research studies of fetal growth) and non-shaded rows refer to retrospective studies (data abstracted from existing routine obstetric records) in this and subsequent tables. Restriction was made to singleton, full-term, live-born babies who were measured within seven days of birth. Further details of the original studies can be found in the accompanying paper.

Measurements

Neonatal anthropometry. Birth weight, placental weight, crown–heel (CH), crown–rump (CR), and leg length, head, chest, and abdomen circumference, mid–upper-arm circumference (MUAC), arm muscle area (AMA), triceps and subscapular skinfolds were measured or derived in the neonates (see accompanying paper).

Maternal anthropometry. Height was generally measured without shoes using a stadiometer, but was self-reported in Southampton 4. Weight was measured using digital scales or beam balances. There may have been inconsistencies across studies with regard to clothes worn during measurement. Head, MUAC, and skinfolds were measured using the same techniques as for neonates, with metal, steel, or fiberglass tapes used for the circumferences. These measurements were made before pregnancy, and/or at various times during gestation. We selected 30 weeks' gestation as the timepoint for which data were most complete. Measures at this time were derived using linear regression (for prospective studies with data collected at specific timepoints) or interpolation (for retrospective studies based on antenatal records); Table I shows when the measurements were taken in each study. Body mass index (BMI) was calculated as weight divided by height squared, and AMA was based on the standard formula (22), corrected for bone area (23). Maternal birth weight was available for six studies, although it was self-reported in the four UK studies. It was not known whether the mothers were singleton or multiple births, and their gestational age was not available.

Paternal anthropometry. Where available, height was self-reported in the UK studies, and measured in India and Africa. Weight was only recorded outside the UK.

Gestation, parity, and maternal age. Gestation was derived from the mother's reported last menstrual period, ultrasound scans, or clinical examinations of the newborn; or clinical observation (Imesi only). Parity was recorded in all studies; in the Isle of Man and Aberdeen all mothers studied were primiparous. Maternal age was calculated from maternal and neonatal dates of birth, or taken as the age recorded closest to the delivery.

Table I. Description of the 18 studies.

Study	Setting	Year of birth	Time of maternal measurement (weeks)	Number for mother–baby analyses	Number for father–baby analyses
Southampton 1	Princess Anne Maternity Hospital, Southampton, UK	1992–93	15–42[a]	557	543
Southampton 2	Princess Anne Maternity Hospital, Southampton, UK	1994–96	28[a]	521	511
Southampton 3	Princess Anne Maternity Hospital, Southampton, UK	1987	28–34[a]	376	
Southampton 4	Princess Anne Maternity Hospital, Southampton, UK	1985	6–20[a]	102	98
Farnborough	Farnborough Hospital, Farnborough, Kent, UK	1975–77	1–41[b]	1,677	
Isle of Man	Nobles Isle of Man Hospital, Isle of Man, UK	1991–92	1–36[a]	388	385
Aberdeen	Aberdeen Maternity Hospital, Aberdeen, Scotland	1948–54	17–36[b]	233	
Helsinki	Helsinki University Central Hospital, Helsinki, Finland	1924–33	N/A	5,979	
Mysore 1	Holdsworth Memorial Hospital, Mysore, South India	1938–95	9–41[b]	1,071	690
Mysore 2	Holdsworth Memorial Hospital, Mysore, South India	1997–98	28–32[a]	597	496
Pune 1	6 rural villages, 50km from Pune, India	1994–96	28[a]	633	599
Pune 2	King Edward Memorial Hospital, Pune, India	1998	N/A	258	
Kandy	Kandy Hospital, Kandy, Sri Lanka	1985	27–42[a]	446	
Beijing	Peking Union Medical College Hospital, Beijing, China	1948–54	6–42[b]	2,421	
Kasaji	Kasaji Hospital, DR Congo, rural Central Africa	1995–98	17–37[b]	338	217
Imesi	Imesi village, rural West Nigeria	1957–58	21–40[b]	266	194
Kingston 1	University Hospital of the West Indies, Kingston, Jamaica	1993–96	21–33[a]	489	
Kingston 2	University Hospital of the West Indies, Kingston, Jamaica	1979–81	29–31[a]	66	
Total				16,418	3,733

[a]30-week values derived using linear regression.
[b]30-week values derived using interpolation.

Statistical analysis

BMI (maternal and paternal), AMA, and triceps had skewed distributions, so medians and interquartile ranges (IQRs) were used to describe all parental measurements. Spearman correlation coefficients were used to assess associations between maternal and paternal variables within each study.

The effects of sex, gestation, parity, and maternal age on neonatal size were examined, and the linearity of the mother– and father–baby relationships checked using regression (comparing quadratic with linear, then if appropriate, linear with no relationships). Individual relationships between each maternal or paternal measurement and neonatal outcome were compared across studies, by testing whether a common regression slope for all studies could be used to summarize each relationship, or whether separate slopes were required for each study (F tests for inclusion of interactions between parental measures and study). Within each study, the effects of IQR increases in each maternal or paternal measurement on each neonatal measure were compared using regression models. This enabled comparison between parental measurements recorded in different units (e.g. maternal height and maternal skinfolds). Six combinations of measurements were used in regression models as not all were recorded in every study: (a) maternal height and BMI (available in most studies), (b) maternal height, head circumference, AMA, and triceps (separating the main components of BMI: skeleton, muscle, and fat), (c)

maternal height, AMA and triceps (both Kasaji and Kingston 2 included measures of muscle and fat but not head circumference), (d) maternal birth weight, height, head circumference, AMA, and triceps (all the maternal components), (e) maternal and paternal height and BMI (the only paternal measures available), and (f) maternal and paternal height (paternal BMI was not available in the UK studies).

Within each study, regression models were used to calculate the percentage of variation in neonatal measures accounted for by parental variables. The extent to which geographical differences in neonatal phenotype were accounted for by differences in their parents' phenotype was examined using mean birth measurements in each study. These were compared, first without adjustment for the parental variables, and then using constrained linear regression to estimate what the values would have been if the parents were the same size in all studies.

All regression models were adjusted for sex and gestation where possible, and mother–baby analyses were repeated adjusting also for parity and maternal age. Studies may have included siblings, so not all parent–baby pairs were independent. In some studies it was not possible to identify siblings, but where it was possible there were generally very few, and these tended to be part of the larger studies. The highest proportion of siblings (21%) was in Beijing; data from this study were analyzed with and without accounting for the dependence between sibling pairs, and the findings were almost identical. Where possible, effect sizes rather than p-values (reliant on sample sizes, which varied widely across the studies) were used to interpret results. All analyses were undertaken with Stata version 7.0.

Results

Maternal and paternal size

Table II summarizes maternal and paternal anthropometry within each study, and shows the IQR ranges across the studies. European and Jamaican mothers were the largest in most measures, while those from India and Sri Lanka were the smallest. Maternal birth weight was between 50 and 340 g lower than that of the female offspring, depending on the study (data not shown). Fathers from the UK were the tallest; BMI was not available in these populations. Within India and Africa, those from Mysore and Imesi were taller and heavier than those from Pune and Kasaji. Correlations between maternal and paternal height ranged from 0.02 (Nigeria) to 0.28, and were highest in India (0.18–0.28). In the UK the correlations were between 0.03 and 0.12. BMI correlations ranged from 0.10 to 0.24 (not available in the UK). Maternal age, gestation, parity, and neonatal anthopometry within each study are shown in the accompanying paper.

Mother to baby relationships

All analyses are presented after adjusting for sex and gestation. Findings were similar if additional adjustment was made for parity and maternal age.

Comparison of mother–baby relationships across studies. The effects of each maternal measurement on each neonatal outcome were compared across studies (data not shown). The maternal variables had mainly positive effects on the neonatal measures, and these were often similar across the studies. The effects on neonatal outcomes were generally similar for maternal head circumference and skinfold thickness across the studies. However, there were stronger relationships with some of the neonatal measures for maternal height, BMI (Figure 1) and birth weight in the developing countries, and for maternal AMA in Kasaji.

Comparison of components of maternal body composition effects on neonatal phenotype. IQR increases in all the maternal variables, particularly maternal birth weight in Mysore, had important effects on the neonatal measures. They were generally little changed by simultaneous adjustment for other maternal variables (Table IIIa and Table IIIb for five of the neonatal outcomes). Within each study, the effects of an IQR increase in maternal height were similar to that of an IQR increase in BMI. Maternal height generally had the strongest effect on neonatal length, and maternal head on neonatal head circumference in all the studies. Maternal skinfold thickness was the strongest predictor of neonatal skinfolds in Mysore and Kasaji, but not Pune. Maternal AMA effects were relatively weak, except in Kasaji. When maternal birth weight was also included in the model, it was among the strongest predictors of all neonatal measurements (Mysore 2 and Southampton 2 only).

Comparison of neonatal phenotype after adjusting for variations in maternal size. Each maternal variable accounted for between 2 and 15% of the variation in neonatal birth weight within studies (data not shown). Eight to 25% of the variation was explained by the combinations of the adult maternal

Table II. Median (IQR) maternal and paternal anthropometric measurements in each of the 18 studies.

	Maternal						Paternal	
Study	Height (cm)	BMI[b] (kg/m^2)	Head (cm)	AMA[b] (cm^2)	Triceps[b] (mm)	Birth weight (g)	Height (cm)	BMI (kg/m^2)
Southampton 1, UK	163 (159, 167)	26.5 (24.2, 29.5)	54.8 (53.9, 55.8)			3,288 (2,948, 3,657)[a]	178 (173, 183)[a]	
Southampton 2, UK	163 (160, 168)	26.8 (24.5, 30.2)	55.3 (54.3, 56.3)	32.1 (27.9, 37.2)	19.6 (15.6, 24.9)	3,260 (2,910, 3,629)[a]	176 (171, 181)[a]	
Southampton 3, UK	163 (158, 168)	26.8 (24.4, 30.1)						
Southampton 4, UK	165 (160, 168)[a]	24.5 (22.1, 27.5)				3,303 (2,927, 3,629)[a]	178 (175, 183)[a]	
Farnborough, UK	163 (159, 168)	24.7 (23.0, 26.6)						
Isle of Man, UK	163 (159, 167)	22.8 (21.0, 25.2)				3,289 (2,948, 3,629)[a]	175 (172, 183)[a]	
Aberdeen, UK	158 (154, 161)	24.8 (23.0, 26.5)						
Helsinki, Finland	158 (154, 162)							
Mysore 1, India	152 (148, 156)	21.4 (19.7, 23.3)				2,720 (2,440, 3,008)	166 (162, 171)	23.6 (20.8, 26.4)
Mysore 2, India	155 (151, 158)	23.3 (21.0, 25.9)	53.5 (52.4, 54.5)	21.4 (18.5, 24.4)	16.8 (12.3, 24.4)	2,807 (2,523, 3,033)	167 (163, 171)	23.1 (20.3, 25.5)
Pune 1, rural India	152 (149, 156)	20.3 (19.2, 21.5)	52.2 (51.3, 53.2)	24.2 (21.0, 26.7)	9.0 (7.1, 11.3)		165 (161, 169)	19.0 (17.6, 20.8)
Pune 2, India	153 (149, 157)		53.6 (51.9, 55.0)					
Kandy, Sri Lanka	151 (147, 155)	20.0 (18.7, 22.2)						
Beijing, China	155 (152, 159)	23.6 (22.0, 25.2)						
Kasaji, rural DR Congo	154 (151, 159)	21.7 (20.3, 23.4)		24.8 (21.9, 28.5)	11.0 (8.8, 13.6)		164 (160, 169)	19.5 (18.3, 20.7)
Imesi, rural Nigeria	160 (155, 163)	21.6 (20.4, 22.7)					170 (165, 173)	21.4 (20.4, 22.9)
Kingston 1, Jamaica	164 (159, 167)	26.9 (24.0, 30.2)			17.4 (13.0, 22.8)			
Kingston 2, Jamaica	163 (157, 165)	24.1 (22.6, 27.0)		34.6 (31.1, 42.0)	10.2 (8.6, 14.2)			
Range of IQRs	7–10 cm	2–6 kg/m^2	2–3 cm	6–11 cm^2	4–12 mm	500–750 g	8–10 cm	2–5 kg/m^2

[a]Self-reported values.
[b]Derived at 30 weeks' gestation.

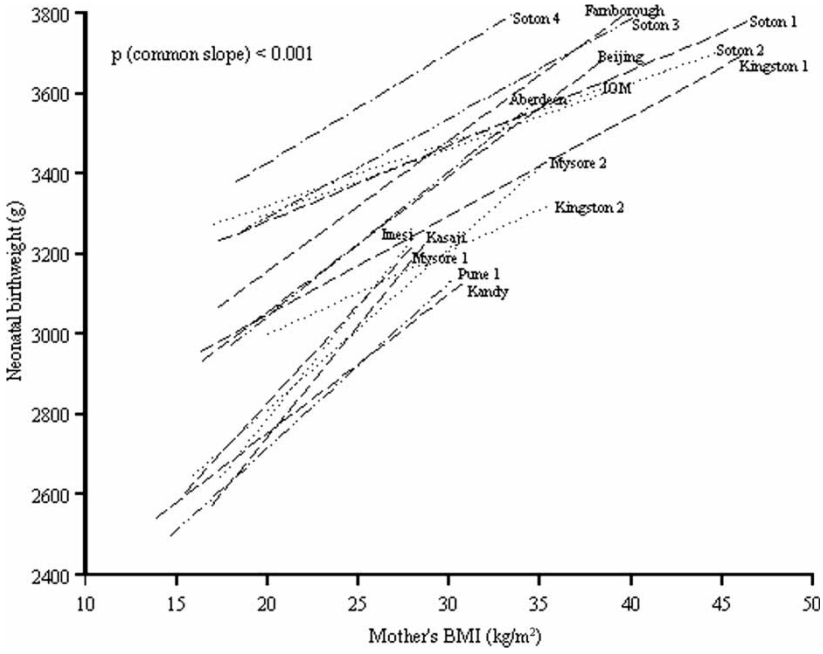

Figure 1. Maternal 30-week BMI effect on neonatal birth weight, by study.

variables, and if maternal birth weight was included, 12 and 45% of the variation was explained in Southampton 2 and Mysore 2 respectively. As described in the accompanying paper, UK neonates were largest for all measures, those in India, Sri Lanka, and Africa smallest, and those in China and Jamaica similar to the overall means based on all studies for each neonatal measure (Table IV for five neonatal outcomes based on a selection of the studies). However, after adjustment for maternal height and BMI, these differences were substantially reduced. For example, birth weight differences from the overall mean were reduced by up to 200 g in each study (Figure 2). Adjustment for the other sets of maternal measures did not further reduce these differences (data not shown).

Father to baby relationships

Paternal height and BMI were mainly positively related to the neonatal measures (data not shown). In contrast to mother–baby relationships, common slopes could adequately represent all relationships with paternal height, and most with paternal BMI. However, separate slopes were required for relationships between paternal BMI and neonatal birth weight, CH length, head and chest circumference, due to contrasting effects in the two African studies (stronger positive effects in Kasaji, negative but weaker effects in Imesi).

Comparison of parental effects

Table IIIc shows the simultaneous effects of maternal and paternal heights and BMIs (India and Africa), and maternal and paternal heights (UK, India, and Africa), on five of the neonatal outcomes. Paternal effects were mainly weaker than maternal effects, although the differences were least for paternal height and neonatal skeletal measures.

Maternal and paternal height together accounted for between 3 and 12% of the variation in the neonatal birth weight within each study. If the BMIs of both parents were also included, explanation of variation increased to 10–22%. Adjusting for parental height substantially reduced differences in neonatal size between studies (Table IV, for five neonatal outcomes in a selection of studies). Additional adjustment for parental BMI also reduced differences in neonates, although these reductions appeared smaller than adjustment for maternal height and BMI alone as the UK studies could not be included in the analyses. If the same studies were included in each analysis, birth weight differences from the overall mean were reduced by up to 60 g after adjustment for maternal variables, 30 g for paternal variables, and 70 g for both.

Discussion

This study has demonstrated important relationships between anthropometric measures of parental size and newborn size in a wide variety of populations.

Table IIIa. Simultaneous effects of IQR increases in maternal height and BMI on five neonatal measurements.

	Maternal measures	Neonatal birth weight (g)	CH length (cm)	Neonatal head (cm)	Neonatal MUAC (cm)	Neonatal subscapular (mm)
Southampton 1, UK	Height	**127.2** (83.2, 171.2)	**0.56** (0.40, 0.72)	**0.24** (0.16, 0.40)	**0.16** (0.08, 0.24)	
	BMI[a]	**101.2** (56.7, 145.8)	**0.32** (0.16, 0.48)	**0.32** (0.16, 0.42)	**0.21** (0.16, 0.32)	
Southampton 2, UK	Height	**99.8** (56.3, 143.3)	**0.60** (0.45, 0.83)	**0.15** (0.08, 0.30)	**0.08** (0.00, 0.15)	
	BMI[a]	**112.3** (65.6, 159.6)	**0.17** (−0.02, 0.34)	**0.29** (0.17, 0.45)	**0.23** (0.11, 0.34)	
Southampton 3, UK	Height	**200.0** (132.0, 267.0)	**1.00** (0.80, 1.30)	**0.40** (0.20, 0.60)	**0.20** (0.10, 0.40)	**0.10** (−0.04, 0.30)
	BMI[a]	**157.9** (99.1, 217.3)	**0.39** (0.11, 0.62)	**0.39** (0.22, 0.56)	**0.22** (0.11, 0.39)	**0.28** (0.11, 0.45)
Southampton 4, UK	Height	**105.6** (0.8, 210.4)	**0.40** (−0.16, 0.88)	**0.16** (−0.08, 0.48)	**0.08** (−0.16, 0.32)	
	BMI[a]	**162.0** (44.8, 279.2)	**0.11** (−0.43, 0.70)	**0.49** (0.16, 0.76)	**0.38** (0.16, 0.65)	
Farnborough, UK	Height	**149.5** (120.2, 178.9)	**0.71** (0.53, 0.89)	**0.36** (0.27, 0.45)		
	BMI[a]	**131.0** (108.0, 154.4)	**0.50** (0.36, 0.65)	**0.32** (0.25, 0.40)		
Isle of Man, UK	Height	**154.7** (98.0, 212.2)	**0.57** (0.41, 0.89)	**0.24** (0.08, 0.41)		
	BMI[a]	**63.0** (10.5, 115.9)	**0.08** (−0.13, 0.29)	**0.17** (0.02, 0.29)		
Aberdeen, UK	Height	**104.1** (34.2, 173.3)				
	BMI[a]	**121.0** (54.7, 187.0)				
Mysore 1, India	Height	**225.6** (52.8, 398.4)	**0.88** (−0.16, 2.00)	**−0.56** (−1.68, 0.56)		
	BMI[a]	**267.5** (104.8, 430.2)	**1.91** (0.83, 3.02)	**−0.32** (−1.55, 0.90)		
Mysore 2, India	Height	**63.7** (25.2, 102.9)	**0.42** (0.21, 0.56)	**0.14** (0.03, 0.28)	**0.07** (−0.02, 0.14)	**0.07** (−0.07, 0.14)
	BMI[a]	**209.2** (167.1, 251.4)	**0.59** (0.34, 0.78)	**0.49** (0.34, 0.64)	**0.34** (0.25, 0.44)	**0.34** (0.25, 0.44)
Pune 1, rural India	Height	**71.4** (37.1, 106.4)	**0.63** (0.42, 0.77)	**0.14** (−0.01, 0.21)	**0.14** (0.03, 0.21)	**0.01** (−0.07, 0.07)
	BMI[a]	**92.7** (61.0, 124.2)	**0.23** (0.05, 0.39)	**0.25** (0.16, 0.37)	**0.14** (0.07, 0.23)	**0.09** (0.01, 0.18)
Kandy, Sri Lanka	Height	**155.2** (101.6, 208.8)	**1.28** (0.80, 1.76)	**0.40** (0.08, 0.72)		
	BMI[a]	**139.7** (82.1, 196.9)	**0.72** (0.29, 1.19)	**0.32** (0.01, 0.72)		
Beijing, China	Height	**132.6** (108.8, 157.1)	**0.61** (0.48, 0.75)	**0.34** (0.20, 0.41)		
	BMI[a]	**138.2 (113.9, 162.9)**	**0.48** (0.35, 0.61)	**0.32** (0.22, 0.42)		
Kasaji, rural DR Congo	Height	**145.1** (96.7, 193.4)	**0.62** (0.39, 0.86)	**0.16** (0.02, 0.31)	**0.23** (0.08, 0.31)	**0.08** (−0.04, 0.23)
	BMI[a]	**152.8** (100.4, 205.2)	**0.56** (0.31, 0.84)	**0.40** (0.25, 0.56)	**0.25** (0.12, 0.34)	**0.19** (0.06, 0.31)
Imesi, rural Nigeria	Height	**130.7** (69.9, 192.3)	**0.61** (0.23, 0.99)	**0.30** (0.03, 0.53)		
	BMI[a]	**119.6** (61.0, 178.3)	**0.28** (−0.07, 0.64)	**0.30** (0.07, 0.55)		
Kingston 1, Jamaica	Height	**88.8** (33.2, 143.6)	**0.58** (0.25, 0.83)	**0.17** (−0.02, 0.33)	**0.08** (−0.08, 0.17)	
	BMI[a]	**147.6** (92.7, 201.9)	**0.61** (0.31, 0.98)	**0.37** (0.18, 0.55)	**0.31** (0.18, 0.43)	
Kingston 2, Jamaica	Height	**189.6** (29.6, 349.6)	**1.60** (0.24, 2.96)	**0.64** (−0.16, 1.36)		
	BMI[a]	**135.0** (−28.8, 299.3)	**0.50** (−0.90, 1.89)	**−0.09** (−0.86, 0.68)		

Values are changes in neonatal measure per IQR increase in maternal variable (95% confidence intervals).
[a]Derived at 30 weeks' gestation.

Table IIIb. Simultaneous effects of IQR increases in maternal height, head, AMA, triceps, and birth weight on five neonatal measurements.

	Maternal measures	Neonatal birth weight (g)	CH length (cm)	Neonatal head (cm)	Neonatal MUAC (cm)	Neonatal subscapular (mm)
Southampton 2, UK	Height	**75.8** (30.0, 122.3)	**0.59** (0.41, 0.75)	**0.08** (−0.08, 0.23)	**0.08** (−0.08, 0.15)	
	Head	**42.2** (−12.0, 96.2)	**0.10** (−0.12, 0.32)	**0.24** (0.08, 0.38)	**0.04** (−0.06, 0.16)	
	AMAa	**−22.1** (−69.9, 25.8)	**−0.28** (−0.46, −0.09)	**0.01** (−0.12, 0.14)	**0.00** (−0.09, 0.09)	
	Tricepsa	**110.7** (59.5, 161.8)	**0.37** (0.19, 0.56)	**0.19** (0.09, 0.37)	**0.19** (0.09, 0.28)	
Mysore 2, India	Height	**20.3** (−23.8, 64.4)	**0.28** (0.05, 0.50)	**0.01** (−0.14, 0.14)	**0.00** (−0.07, 0.07)	**0.02** (−0.07, 0.14)
	Head	**53.3** (2.3, 104.2)	**0.13** (−0.15, 0.38)	**0.27** (0.13, 0.44)	**0.08** (−0.02, 0.19)	**−0.04** (−0.15, 0.08)
	AMA[a]	**57.8** (16.5, 99.7)	**0.12** (−0.12, 0.35)	**0.18** (0.06, 0.30)	**0.12** (0.01, 0.18)	**0.12** (0.01, 0.18)
	Triceps[a]	**139.1** (87.8, 191.5)	**0.37** (0.12, 0.61)	**0.24** (0.12, 0.37)	**0.24** (0.12, 0.37)	**0.37** (0.24, 0.49)
Pune 1, India	Height	**55.3** (17.5, 93.1)	**0.54** (0.34, 0.74)	**0.03** (−0.07, 0.14)	**0.07** (−0.03, 0.14)	**−0.07** (−0.14, 0.07)
	Head	**44.8** (10.3, 79.4)	**0.38** (0.19, 0.55)	**0.30** (0.19, 0.38)	**0.13** (0.06, 0.23)	**0.10** (0.00, 0.17)
	AMA[a]	**−0.6** (−36.5, 35.9)	**−0.17** (−0.34, 0.06)	**−0.06** (−0.17, 0.06)	**0.00** (−0.11, 0.11)	**0.06** (−0.06, 0.17)
	Triceps[a]	**16.8** (−15.5, 48.7)	**−0.04** (−0.21, 0.13)	**0.04** (−0.04, 0.17)	**0.02** (−0.08, 0.08)	**0.01** (−0.08, 0.08)
Southampton 2, UK	Height	**88.5** (45.8, 132.0)	**0.60** (0.45, 0.83)	**0.15** (0.02, 0.23)	**0.08** (−0.03, 0.15)	
	AMA[a]	**−16.6** (−64.4, 30.4)	**−0.28** (−0.46, −0.09)	**0.04** (−0.09, 0.18)	**0.01** (−0.09, 0.09)	
	Triceps[a]	**116.3** (66.0, 167.4)	**0.37** (0.19, 0.56)	**0.28** (0.09, 0.37)	**0.19** (0.09, 0.28)	
Mysore 2, India	Height	**35.0** (−5.6, 76.3)	**0.35** (0.14, 0.56)	**0.07** (−0.07, 0.21)	**0.01** (−0.07, 0.14)	**0.00** (−0.09, 0.10)
	AMA[a]	**60.8** (21.2, 100.3)	**0.12** (−0.12, 0.30)	**0.18** (0.06, 0.30)	**0.12** (0.03, 0.18)	**0.11** (0.02, 0.20)
	Triceps[a]	**147.6** (100.0, 196.4)	**0.37** (0.12, 0.61)	**0.37** (0.12, 0.49)	**0.24** (0.12, 0.37)	**0.29** (0.18, 0.40)
Pune 1, rural India	Height	**63.7** (26.6, 100.8)	**0.63** (0.42, 0.77)	**0.07** (−0.07, 0.21)	**0.07** (0.01, 0.21)	**−0.02** (−0.11, 0.08)
	AMA[a]	**10.3** (−25.7, 45.6)	**−0.06** (−0.29, 0.11)	**0.01** (−0.11, 0.11)	**0.03** (−0.06, 0.11)	**0.07** (−0.02, 0.16)
	Triceps[a]	**19.3** (−12.2, 51.2)	**−0.01** (−0.17, 0.17)	**0.08** (−0.04, 0.21)	**0.03** (−0.04, 0.13)	**0.02** (−0.06, 0.10)
Kasaji, rural DR Congo	Height	**114.7** (46.8, 182.5)	**0.70** (0.31, 1.01)	**0.08** (−0.16, 0.31)	**0.16** (−0.02, 0.23)	**0.02** (−0.14, 0.17)
	AMA[a]	**106.9** (33.0, 180.2)	**0.46** (0.13, 0.86)	**0.33** (0.13, 0.59)	**0.20** (0.03, 0.33)	**0.03** (−0.14, 0.19)
	Triceps[a]	**69.6** (−0.5, 144.1)	**0.20** (−0.20, 0.54)	**0.05** (−0.20, 0.29)	**0.05** (−0.10, 0.20)	**0.06** (−0.11, 0.23)
Kingston 2, Jamaica	Height	**173.6** (2.4, 344.8)	**1.44** (−0.08, 2.88)	**0.56** (−0.24, 1.36)		
	AMA[a]	**42.5** (−135.2, 221.3)	**0.33** (−1.31, 1.96)	**−0.04** (−0.98, 0.87)		
	Triceps[a]	**127.1** (−63.3, 317.5)	**0.28** (−1.46, 1.96)	**0.01** (−0.95, 1.01)		
Southampton 2, UK	Height	**48.8** (−0.40, 97.5)	**0.45** (0.30, 0.68)	**−0.02** (−0.15, 0.15)	**−0.02** (−0.08, 0.08)	
	Head	**23.0** (−32.8, 78.8)	**0.04** (−0.20, 0.26)	**0.22** (0.08, 0.38)	**0.02** (−0.10, 0.14)	
	AMA[a]	**−11.0** (−59.8, 38.6)	**−0.18** (−0.37, −0.01)	**0.04** (−0.09, 0.18)	**0.02** (−0.09, 0.09)	
	Triceps[a]	**103.2** (51.2, 155.3)	**0.28** (0.09, 0.56)	**0.19** (0.09, 0.37)	**0.19** (0.09, 0.28)	
	Birth weight	**96.7** (49.6, 143.9)	**0.34** (0.14, 0.53)	**0.14** (0.01, 0.26)	**0.20** (0.11, 0.29)	
Mysore 2, India	Height	**−160.3** (−266.7, −53.2)	**−0.14** (−0.77, 0.49)	**0.01** (−0.28, 0.35)	**−0.28** (−0.56, 0.02)	**−0.42** (−0.84, 0.11)
	Head	**112.1** (7.1, 217.1)	**0.32** (−0.29, 0.90)	**0.40** (0.11, 0.71)	**0.17** (−0.11, 0.44)	**−0.10** (−0.45, 0.25)
	AMA[a]	**113.9** (−7.1, 235.4)	**0.12** (−0.53, 0.83)	**0.24** (−0.12, 0.65)	**0.18** (−0.12, 0.53)	**0.44** (−0.22, 1.10)
	Triceps[a]	**148.8** (25.6, 272.1)	**0.37** (−0.24, 1.10)	**0.37** (0.01, 0.73)	**0.37** (0.01, 0.61)	**2.20** (−0.06, 0.55)
	Birth weight	**253.8** (155.4, 352.2)	**0.88** (0.32, 1.44)	**0.54** (0.25, 0.83)	**0.68** (0.43, 0.94)	**0.43** (0.04, 0.84)

Values are changes in neonatal measure per IQR increase in maternal variable (95% confidence intervals).
[a]Derived at 30 weeks' gestation.

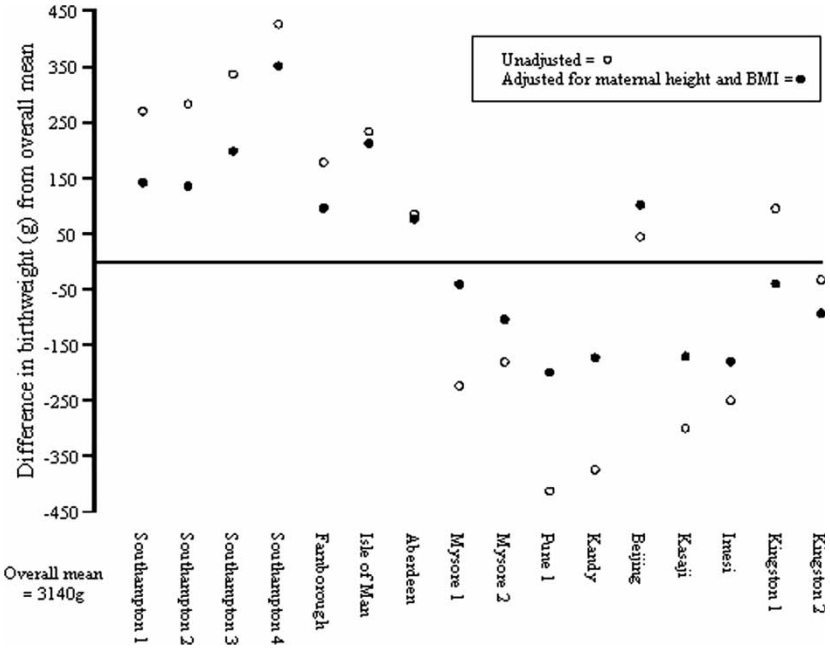

Figure 2. Study effects on neonatal birth weight, before and after adjusting for maternal height and 30-week BMI.

The strengths of the study are the synthesis of data from different geographical locations around the world, the use of methods that enabled comparison of effect sizes between different components of parental and neonatal body composition and between mother-baby and father-baby relationships, and the ability to take parity and gestational age at birth into account.

Differences in neonatal size between populations were considerably reduced after adjustment for maternal body composition. Other factors such as maternal diet, physical activity, smoking, alcohol consumption, illness, and social class would vary across populations, and these along with genetic and epigenetic mechanisms are likely to be important sources of variation between populations. The absence of data on these factors in many of our studies, or the wide variety of methods used to collect such data, precluded adjustment for these. The variation in birth weight explained by social class was 0.1% in Pune, India, 1.7% in Southampton, UK, 4.9% in Kandy, Sri Lanka, and 11.3% in Kasaji, Congo. Knowledge of individual components of maternal body composition such as muscle and fat did not explain geographical differences any better than height and BMI alone. Crude measurements of soft tissue at only one site such as the arm, at one timepoint in late pregnancy, may not distinguish between populations as well as a measure of total mass such as BMI. Effects of adjusting for maternal body composition may be greater if more sophisticated measurements of muscle and fat were used, and if measurements before pregnancy or in early pregnancy, and *changes* in measurements during pregnancy, were available. Adjustment for paternal as well as maternal height and BMI reduced geographical differences in neonatal phenotype further, but the data did not allow adjustment for more detailed measurements of paternal body composition.

Within each study, all measures of maternal size and body composition were related to neonatal phenotype. Maternal birth weight was one of the strongest predictors of neonatal size in Mysore, India and, as previously described, in Southampton, UK (24), and showed independent associations with offspring birth length, head circumference, and MUAC as well as with birth weight. Few other studies have examined the relationship of maternal birth weight to offspring neonatal measurements other than birth weight, but a study from Guatemala also showed significant associations between maternal birth weight and offspring birth length (25). In most of the populations in our study, the effects of maternal height were similar in magnitude to those of maternal BMI. Previous analyses have generally compared effects of maternal height and weight. In a meta-analysis based on 25 studies in both developed and developing countries, maternal weight, which is a summary measure of all aspects of maternal body composition, was found to be a stronger predictor of offspring birth weight than maternal height (2). Our data suggest that the mother's skeletal size and soft tissue mass have independent effects on birth weight.

Table IIIc. Simultaneous effects of IQR increases in maternal and paternal height and BMI on five neonatal measurements.

		Neonatal birth weight (g)	CH length (cm)	Neonatal head (cm)	Neonatal MUAC (cm)	Neonatal subscapular (mm)
Mysore 2, India	Maternal height	**41.7** (−3.0, 86.5)	**0.29** (0.06, 0.52)	**0.07** (−0.07, 0.22)	**0.07 (−0.04, 0.17)**	**0.06** (−0.05, 0.17)
	Maternal BMI[a]	**182.2** (136.0, 228.3)	**0.50** (0.26, 0.75)	**0.42** (0.27, 0.56)	**0.34 (0.23, 0.44)**	**0.34** (0.23, 0.46)
	Paternal height	**42.3 (−2.8, 87.3)**	**0.36** (0.13, 0.60)	**0.09** (−0.05, 0.23)	**0.04 (−0.07, 0.15)**	**0.01** (−0.10, 0.11)
	Paternal BMI	**46.2** (−5.5, 97.8)	**0.04** (−0.23, 0.31)	**0.21** (0.04, 0.37)	**0.12 (0.00, 0.24)**	**0.04** (−0.08, 0.16)
Pune 1, rural India	Maternal height	**67.8** (31.5, 104.0)	**0.53** (0.34, 0.73)	**0.09** (−0.03, 0.22)	**0.10 (0.01, 0.20)**	**0.01** (−0.09, 0.10)
	Maternal BMI[a]	**84.7** (49.8, 119.6)	**0.15** (−0.03, 0.34)	**0.22** (0.10, 0.34)	**0.12 (0.03, 0.21)**	**0.08** (−0.01, 0.17)
	Paternal height	**19.1** (−13.8, 52.1)	**0.31** (0.13, 0.49)	**0.14** (0.03, 0.25)	**0.09 (0.01, 0.18)**	**−0.03** (−0.11, 0.06)
	Paternal BMI	**33.3** (1.2, 65.4)	**0.11** (−0.07, 0.28)	**0.04** (−0.06, 0.15)	**0.07 (−0.01, 0.16)**	**0.04** (−0.05, 0.12)
Kasaji, rural DR Congo	Maternal height	**114.0** (52.1, 175.9)	**0.51** (0.22, 0.81)	**0.12** (−0.07, 0.32)	**0.14 (0.01, 0.27)**	**0.06** (−0.09, 0.22)
	Maternal BMI[a]	**118.9** (54.7, 183.2)	**0.56** (0.26, 0.86)	**0.35** (0.15, 0.54)	**0.17 (0.03, 0.31)**	**0.05** (−0.11, 0.22)
	Paternal height	**45.4** (−23.4, 114.4)	**0.14** (−0.19, 0.46)	**0.11** (−0.09, 0.32)	**0.11 (−0.04, 0.26)**	**0.04** (−0.13, 0.22)
	Paternal BMI	**89.6** (33.6 145.7)	**0.36** (0.10, 0.63)	**0.18** (0.01, 0.35)	**0.26 (0.00, 0.24)**	**0.12** (−0.03, 0.26)
Imesi, rural Nigeria	Maternal height	**83.9** (35.7, 132.0)	**0.52** (0.28, 0.76)	**0.22** (0.03, 0.41)		
	Maternal BMI[a]	**112.8** (47.6, 178.0)	**0.37** (0.05, 0.69)	**0.43** (0.18, 0.68)		
	Paternal height	**−13.5** (−80.8, 53.7)	**0.17** (−0.17, 0.51)	**0.04** (−0.23, 0.30)		
	Paternal BMI	**5.8** (−67.3, 79.0)	**−0.20** (−0.57, 0.16)	**0.14** (−0.15, 0.43)		
Southampton 1, UK	Maternal height	**119.9** (74.8, 165.0)	**0.50** (0.31, 0.67)	**0.24** (0.12, 0.35)	**0.16 (0.06, 0.26)**	
	Paternal height	**40.0** (−10.5, 90.4)	**0.38** (0.18, 0.59)	**0.13** (0.00, 0.26)	**−0.01 (−0.11, 0.10)**	
Southampton 2, UK	Maternal height	**56.9** (15.5, 98.2)	**0.46** (0.29, 0.62)	**0.11** (0.00, 0.22)	**0.03 (−0.06, 0.11)**	
	Paternal height	**51.2** (1.9, 100.5)	**0.40** (0.19, 0.60)	**0.04** (−0.10, 0.17)	**0.05 (−0.05, 0.15)**	
Southampton 4, UK	Maternal height	**111.9** (6.7, 217.1)	**0.34** (−0.14, 0.82)	**0.10** (−0.16, 0.38)	**0.11 (−0.10, 0.33)**	
	Paternal height	**28.9** (−67.9, 125.7)	**0.52** (0.08, 0.96)	**0.02** (−0.22, 0.28)	**0.01 (−0.19, 0.21)**	
Isle of Man, UK	Maternal height	**142.5** (81.6, 203.5)	**0.58** (0.34, 0.83)	**0.20** (0.04, 0.36)		
	Paternal height	**21.0** (−43.7, 85.5)	**0.18** (−0.08, 0.44)	**0.05** (−0.12, 0.21)		
Mysore 1, India	Maternal height	**73.0** (37.6, 108.4)	**0.27** (0.01, 0.53)	**0.10** (−0.04, 0.24)		
	Paternal height	**73.2** (32.2, 114.1)	**0.20** (−0.10, 0.50)	**0.14** (−0.03, 0.30)		
Mysore 2, India	Maternal height	**26.5** (−20.4, 73.4)	**0.24** (0.01, 0.47)	**0.05** (−0.10, 0.20)	**0.04 (−0.06, 0.15)**	**0.02 (−0.08, 0.13)**
	Paternal height	**46.1** (−2.0, 94.3)	**0.37** (0.14, 0.62)	**0.09** (−0.06, 0.24)	**0.05 (−0.06, 0.15)**	**0.02 (−0.10, 0.13)**
Pune 1, rural India	Maternal height	**65.2** (28.4, 101.9)	**0.53** (0.34, 0.92)	**0.08** (−0.04, 0.20)	**0.11 (0.01, 0.20)**	**0.01 (−0.09, 0.10)**
	Paternal height	**23.9** (−10.1, 58.0)	**0.32** (0.14, 0.50)	**0.16** (0.05, 0.27)	**0.11 (0.02, 0.21)**	**−0.02 (−0.10, 0.06)**
Kasaji, rural DR Congo	Maternal height	**135.0** (71.2, 198.7)	**0.62** (0.32, 0.92)	**0.17** (−0.02, 0.36)	**0.17 (0.04, 0.30)**	**0.08 (−0.07, 0.24)**
	Paternal height	**71.1** (−0.4, 142.5)	**0.26** (−0.08, 0.59)	**0.17** (−0.04, 0.38)	**0.14 (0.00, 0.29)**	**0.07 (−0.10, 0.24)**
Imesi, rural Nigeria	Maternal height	136.5 (67.7, 205.3)	**0.69** (0.34, 1.04)	**0.20** (−0.08, 0.46)		
	Paternal height	−13.6 (−74.1, 46.8)	**0.24** (−0.08, 0.56)	**0.05** (−0.20, 0.29)		

Values are changes in neonatal measure per IQR increase in parental variable (95% confidence intervals).
[a]Derived at 30 weeks' gestation.

Table IV. Study differences from the overall mean for five neonatal measures, before and after adjusting for maternal and paternal height and BMI.

		Neonatal birth weight (g)	CH length (cm)	Neonatal head (cm)	Neonatal MUAC (cm)	Neonatal subscapular (mm)
	Overall means	3,140 g	49.5 cm	33.8 cm	10.7 cm	4.4cm
Southampton 1, UK	Unadjusted	269.7	0.62	1.26	0.91	
	Adjusted[a]	**141.1**	**0.12**	**0.97**	**0.72**	
Mysore 2, India	Unadjusted	−180.9	−0.31	0.26	−0.29	0.17
	Adjusted[a]	**−104.2**	**0.05**	**0.42**	**−0.22**	**0.21**
Kandy, Sri Lanka	Unadjusted	−373.9	−1.23	−0.19		
	Adjusted[a]	**−173.2**	**−0.34**	**0.29**		
Beijing, China	Unadjusted	43.8	0.16	−1.76		
	Adjusted[a]	**101.0**	**0.43**	**−1.64**		
Kasaji, rural DR Congo	Unadjusted	−299.9	−1.64	0.27	−1.16	−0.55
	Adjusted[a]	**−171.1**	−1.12	0.56	−0.97	−0.41
Imesi, rural Nigeria	Unadjusted	−250.0	−1.69	0.19		
	Adjusted[a]	**−179.9**	**−1.51**	**0.37**		
Kingston 1, Jamaica	Unadjusted	94.5	0.45	0.81	−0.27	
	Adjusted[a]	**−40.1**	**−0.08**	**0.50**	**−0.46**	
	Overall means	2,843 g	48.4 cm	33.8 cm	10.0 cm	4.3cm
Mysore 2, India	Unadjusted	107.0	0.74	0.28	0.41	0.25
	Adjusted[b]	**43.5**	**0.52**	**0.11**	**0.29**	**0.15**
Kasaji, rural DR Congo	Unadjusted	21.9	−0.50	0.36	−0.42	−0.45
	Adjusted[b]	**31.1**	**−0.41**	**0.39**	**−0.39**	**−0.43**
Imesi, rural Nigeria	Unadjusted	40.6	−0.88	0.19		
	Adjusted[b]	**−23.9**	**−1.23**	**0.06**		
	Overall means	3,092 g	49.1 cm	34.4 cm	10.7 cm	4.3 cm
Southampton 1, UK	Unadjusted	316.8	0.98	0.69	0.89	
	Adjusted[c]	**229.7**	**0.45**	**0.55**	**0.78**	
Mysore 2, India	Unadjusted	−141.4	0.03	−0.32	−0.31	0.25
	Adjusted[c]	**−97.8**	**0.32**	**−0.26**	**−0.26**	**0.24**
Kasaji, rural DR Congo	Unadjusted	−226.2	−1.20	−0.25	−1.13	−0.45
	Adjusted[c]	**−172.0**	**−0.87**	**−0.15**	**−1.05**	**−0.45**
Imesi, rural Nigeria	Unadjusted	−169.7	−1.40	−0.35		
	Adjusted[c]	**−183.4**	**−1.45**	**−0.38**		

Values are regression coefficients for each study, unadjusted then adjusted for maternal and paternal height and BMI (adjusted in bold) (maternal BMI derived at 30 weeks' gestation).
Constants in models are constrained to equal mean neonatal values.
[a]Adjusted for maternal height and BMI.
[b]Adjusted for maternal and paternal height and BMI.
[c]Adjusted for maternal and paternal height.

As previously reported from the study in Pune, India, included in this analysis (15), the mother's adult measurements predicted 'like' measurements in the newborns. Thus maternal height was generally the strongest predictor of neonatal length, maternal head circumference of neonatal head circumference, and maternal skinfold thickness of neonatal skinfolds. Neggers et al. reported a similar phenomenon in US mothers and babies for height/length and skinfolds (26) and, although they did not compare effect sizes with other maternal measurements, others have described significant associations between maternal height and newborn length (25), and maternal and neonatal skinfolds (27–31). Maternal head circumference has been measured in few studies, and relationships with neonatal head size have not been described previously. Except in one population (Kasaji, DR Congo), 'like with like' relationships were not seen for measures of maternal and neonatal muscle (MUAC and AMA). This may be because MUAC is a difficult measurement in newborns, and the formula used to derive AMA in neonates does not correct for bone size. However, two previous studies, one from the USA and another from Peru, showed significant positive associations between maternal and neonatal MUAC or AMA

(26,29). The importance of maternal muscularity as a predictor of newborn size requires more research.

For some of the maternal measures, notably BMI, stronger effects on neonatal phenotype were seen in developing countries. In a review of the literature, Ramakrishnan et al. (25) found maternal birth weight to have a stronger effect on neonatal birth weight in Guatemala than in any UK studies. They speculated that intergenerational effects may be greater in developing countries because women inherit inadequate environments across generations. Another possible environmental factor may be that the effects of the mother's own intrauterine experience have permanent effects on her adult size, the development of her reproductive organs, or her hormonal and metabolic systems. It may also be that women in some developing countries inherit genes that are more similar across generations than in developed countries due to a higher frequency of consanguineous marriage.

As the mother's birth weight reflects her own intrauterine growth, and her height and head circumference reflect her infant and childhood growth, one interpretation of our findings is that the nutrition of a female throughout her life cycle, as well as during pregnancy, may influence the growth of her fetus. If so, our analysis indicates the effect on neonatal size in future generations that might be expected from changes in women's birth weight, height, and BMI due to nutritional improvement. Increases of one IQR in maternal measurements were associated with increases of 10–250 g in offspring birth weight. It could be argued that an IQR change is large and hence unlikely; however increases in height of up to 5 cm between generations have been recorded (32) (IQRs for height ranged from 7 to 10 cm in the populations included in this study) and could result in increases in birth size.

Parental heights, and BMIs where available, were correlated in most of the populations studied, and most strongly in India. This is likely to reflect 'assortative mating' (non-random mating); height is one of the matching criteria often used in arranged marriages. Consistent with a number of other studies (mainly from developed countries and mostly limited to birth weight as the outcome) (33–36), the mother's adult measures generally had stronger effects on neonatal size than paternal measures. There were markedly fewer data from fathers, which limited the comparisons that could be made. Furthermore our analysis may have underestimated paternal effects as paternity was not confirmed in any of the studies. Maternal and paternal BMI measures were not strictly comparable as the maternal values were derived at 30 weeks' gestation so included the weight of the fetus. In some studies maternal height was measured, while paternal height was reported. Stronger maternal effects would be expected, as the father's contribution to neonatal size is mainly genetic, while the mother contributes both genetic and environmental influences. Previous studies, based on correlations between the birth weights of siblings and half-siblings related through either the mother or the father (37), and on studies of pregnancies resulting from ovum donation (38), have suggested that the latter are predominant. However, a number of genetic mutations or polymorphisms have recently been described that are associated with alterations in dimensions at birth (39–41).

As previously reported from one of the Southampton studies included in our analysis (24), differences between maternal and paternal effects were least for measurements of newborn skeletal size. While the associations of maternal BMI with birth weight were generally stronger than those of paternal BMI, associations between paternal height and neonatal length and head circumference were comparable with and sometimes stronger than those of maternal height. In Southampton, because of a strong positive effect of paternal height on birth length but only a weak effect on birth weight, babies of taller fathers had a lower mean ponderal index at birth (24). The same study also showed that while maternal birth weight had a strong positive effect on neonatal ponderal index, paternal birth weight had a strong effect on newborn length. In another recent study from Mysore, not included in this analysis, paternal birth weight had an effect on birth weight similar to that of maternal birth weight, and paternal birth length was more strongly related than maternal birth length to offspring birth length (36). Taken together, these findings suggest strong genetic effects on size at birth, with stronger effects on skeletal measures at birth than on soft tissue components of neonatal body composition. However, the paucity of paternal data, and the small number of studies with detailed neonatal anthropometry, limited the comparisons that could be made between maternal and paternal effects on neonatal measures of muscle and adipose tissue.

This study has shown that geographical differences in newborn phenotype can be accounted for by differences in maternal size and body composition to a large extent. Based on available data, maternal effects on neonatal size appear to be stronger than paternal effects. Future studies using better measurements of maternal body composition, such as dual X-ray absorptiometry (DXA) before pregnancy, and bioimpedance or isotope dilution both before

and during pregnancy, would be informative. More importantly, a better understanding is required of the environmental and genetic mechanisms linking the mother's body composition to neonatal phenotype and both short- and long-term functional outcomes. Information on paternal and genetic influences on neonatal body composition is a glaring deficiency in the literature. Understanding these relationships is important for developing appropriate interventions to achieve the millennium development goal of improving maternal health by 2015 (42). In addition, caution is required when using fetal growth curves from another population in assessing ultrasound data; provision of local population data is therefore of great importance.

Acknowledgements

We would like to thank Professor David Barker, former Director of the Medical Research Council Environmental Epidemiology Unit in Southampton, for facilitating the development of this work. We are extremely grateful to the following who were involved in collecting data for the studies (in alphabetical order by site of study): Dr Tom Forsén (Helsinki data), Dr Anne Lee (Isle of Man data), Dr Minerva Thame, Professor Rainford Wilks, Dr Franklyn Bennett, Dr Jo Hall, Dr Michael Boyne, Dr Jackie Landman (Jamaican data), Dr B.D.R. Paul, Dr Lovesome David, Dr Claudia Stein, Dr S.R. Veena (Mysore data), Professor David Morley (Nigerian data), Dr V.N. Rao, Professor Kurus Coyaji (Pune data), and Mr Tim Wheeler (Southampton data).
The prospective studies were funded by the British Commonwealth Nurses War Memorial Fund (Kasaji), British Heart Foundation (Farnborough), Commonwealth Foundation (Kandy), Dunhill Medical Trust UK (Southampton 1), Medical Research Council UK (Farnborough, Pune 1, Southampton 1, Southampton 2), Parthenon Trust Switzerland (Mysore 2), Postgraduate Medical Centre Nobles Hospital (Isle of Man), UK Department for International Development DfID (Imesi, Kandy), UNICEF (Kandy), University of Manchester UK (Kasaji), WellBeing UK (Southampton 2), Wellcome Trust UK (Kingston 1, Pune 1, Pune 2), and West African Council for Medical Research (Imesi). In India, we would like to acknowledge the support of Sneha-India.

References

1. Barker DJP. Mothers, Babies and Health in Later Life. Edinburgh: Churchill Livingstone; 1998.
2. World Health Organization. Maternal anthropometry and pregnancy outcomes. Bull World Health Organ 1995; S73.
3. Kramer MS. Determinants of low birth weight: methodological assessment and meta-analysis. Bull World Health Organ. 1987;65:663–737.
4. Godfrey KM, Hales CN, Osmond C, Barker DJ, Taylor KP. Relation of cord plasma concentrations of proinsulin, 32–33 split proinsulin, insulin and C-peptide to placental weight, body size and body proportions at birth. Early Hum Dev. 1996;46:129–40.
5. Godfrey KM, Matthews N, Glazier J, Jackson A, Wilman C, Sibley CP. Neutral amino acid uptake by the microvillous plasma membrane of the human placenta is inversely related to fetal size at birth in normal pregnancy. J Clin Endocrinol Metab. 1998;83:3320–6.
6. Dewar A, Clarke S, Diamond I, Wheeler T. The ponderal index of the newborn infant. In: Gati I, editor. Recent Progress in Perinatal Medicine. Budapest: Postgraduate Medical School; 1987. p. 89–93.
7. Wheeler T, Godfrey K, Atkinson C, Badger J, Kay R, Owens R, et al. Disproportionate fetal growth and fingerprint patterns. Br J Obstet Gynaecol. 1998;105:562–4.
8. de Swiet M, Fayers P, Shinbourne EA. Value of repeated blood pressure measurements in children – the Brompton study. Br Med J. 1980;280:1567–9.
9. Lee AM. Size at birth and neonatal fibrinogen. PhD thesis, University of Southampton; 2000.
10. Campbell DM, Hall MH, Barker DJP, Cross J, Shiell AW, Godfrey KM. Diet in pregnancy and the offspring's blood pressure 40 years later. Br J Obstet Gynaecol. 1996;103:273–80.
11. Forsén T, Eriksson JG, Tuomilehto J, Teramo K, Osmond C, Barker DJP. Mother's weight in pregnancy and coronary heart disease in a cohort of Finnish men: follow up study. BMJ. 1997;315:837–40.
12. Stein CE, Fall CHD, Kumaran K, Osmond C, Cox V, Barker DJP. Fetal growth and coronary heart disease in South India. Lancet. 1996;348:1269–73.
13. Hill JC, Krishnaveni GV, Annamma I, Leary SD, Fall CHD. Glucose tolerance in pregnancy in South India: relationships to neonatal anthropometry. Acta Obstet Gynecol Scand. 2005;84(2):159–65.
14. Yajnik CS, Lubree G, Rege SS, Naik SS, Deshpande JA, Despande SS, et al. Adiposity and hyperinsulinemia in Indians are present at birth. J Clin Endocrinol Metab. 2002; 87:5575–80.
15. Yajnik CS, Fall CHD, Coyaji KJ, Hirve SS, Rao S, Barker DJP, et al. Neonatal anthropometry: the thin–fat Indian baby. The Pune Maternal Nutrition Study. Int J Obes. 2003;27: 173–80.
16. Lovel HJ. Maternal nutrition status and pregnancy outcomes in Sinhala Sri Lanka with an analysis of customs and practices in pregnancy and the puerperium associated with nutrition. PhD thesis. University of London; 1996.
17. Mi J, Law C, Zhang K, Osmond C, Stein C, Barker D. Effects of infant birthweight and maternal body mass index in pregnancy on components of the insulin resistance syndrome in China. Ann Intern Med. 2000;132:253–60.
18. Newby RM. Symphysis-fundal height and the influence of placental malaria and poverty on pregnancy outcomes in rural Democratic Republic of Congo. PhD thesis. University of Manchester; 2000.
19. Morley D, Woodland M, Cuthbertson WFJ. Controlled trial of Pyrimethaminc in pregnant women in an African village. Br Med J. 1964;1:667–8.
20. Thame M, Osmond C, Wilks RJ, Bennett FI, McFarlane-Anderson N, Forrester TE. Blood pressure is related to

placental volume and birth weight. Hypertension. 2000;35: 662–7.
21. Landman J, Hall JSE. The dietary habits and knowledge of folklore of pregnant and Jamaican women. Ecol Food Nutr. 1983;12:203–10.
22. Jelliffe DB, Jelliffe EPP. Prevalence of protein-calorie malnutrition in Haitian preschool children. Am J Public Health. 1960;50:1355–66.
23. Heymsfield SB, McManus C, Smith J, Stevens V, Nixon DW. Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. Am J Clin Nut. 1982;36:680–90.
24. Godfrey KM, Barker DJP, Robinson S, Osmond C. Maternal birthweight and diet in pregnancy in relation to the infant's thinness at birth. Br J Obstet Gynaecol. 1997;104:663–7.
25. Ramakrishnan U, Martorell R, Schroeder DG, Flores R. Role of intergenerational effects on linear growth. J Nutr. 1999; Suppl.:544S–9S.
26. Neggers Y, Goldenberg RL, Cliver SP, Hoffman HJ, Cutter GR. The relationship between maternal and neonatal anthropometric measurements in term newborns. Obstet Gynecol. 1995;85:192–6.
27. Sibert JR, Jadhav M, Inbaraj SG. Maternal and fetal nutrition in South India. Br Med J. 1978;1:1517–8.
28. Whitelaw AGL. Influence of maternal obesity on subcutaneous fat in the newborn. Br Med J. 1976;1:985–6.
29. Frisancho AR, Klayman JE, Matos J. Influence of maternal nutritional status on prenatal growth in a Peruvian Urban population. Am J Phys Anthropol. 1977;46:265–74.
30. Swain S, Bhatia BD, Pandey S, Pandey LK, Agrawal A. Birthweight: its relationship with maternal and newborn skinfold thicknesses. Indian Pediatr. 1991;28:259–64.
31. Silliman K, Kretchmer N. Maternal obesity and body composition of the neonate. Biol Neonate. 1995;68:384–93.
32. Sachdev HPS. Nutritional status of children and women in India: recent trends. Bulletin of the Nutritional Foundation of India. 1997;18:1–5.
33. Morrison J, Williams GM, Najman JM, Andersen MJ. The influence of paternal height and weight on birth-weight. Aust N Z J Obstet Gynaecol. 1991;21:114–6.
34. Hennessy E, Alberman E. Intergenerational influences affecting birth outcome I: Birthweight for gestational age in the children of the 1958 British Birth Cohort. Paediatr Perinat Epidemiol. 1998;12(Suppl. 1):45–60.
35. Klebanoff MA, Mednick BR, Schulsinger C, Secher NJ, Shiono PH. Father's effect on infant birth weight. Am J Obstet Gynecol. 1998;178:1022–6.
36. Veena SR, Kumaran K, Swarnagowri MN, Jaykumar MN, Leary SD, Stein CE, et al. Intergenerational effects on size at birth in South India. Paediatr Perinat Epidemiol. 2004;18(5): 361–70.
37. Morton NE. The inheritance of human birthweight. Ann Hum Genet. 1955;20:125–33.
38. Brooks AA, Johnson MR, Steer PJ, Pawson ME, Abdalla HI. Birth weight: nature or nurture? Early Hum Dev. 1995;42: 29–35.
39. Dunger DB, Ong KKL, Huxtable SJ, Sherriff A, Woods KA, Ahmed ML, et al. Association of the INS VNTR with size at birth. Nat Genet. 1998;19:98–100.
40. Frayling TM, Hattersley AT. The role of genetic susceptibility in the association of low birthweight with type2 diabetes. Brit Med Bull. 2001;60:89–101.
41. Vaessen N, Janssen JA, Heutink P, Hofman A, Lamberts SWJ, Oostra BA, et al. Association between genetic variation in the gene for insulin-like-growth factor-I and low birthweight. Lancet. 2002;359:1036–7.
42. http://www.un.org/millenniumgoals.