Journal of Perinatology (2014) 34, 698–704

www.nature.com/jp

ORIGINAL ARTICLE

Antenatal predictors and body composition of large-for-gestational-age newborns: perinatal health outcomes

EL Donnelley[1], CH Raynes-Greenow[2], RM Turner[2], AE Carberry[2] and HE Jeffery[1,2,3]

OBJECTIVE: To compare body composition of large-for-gestational-age (LGA) with appropriate-for-gestational-age (AGA) newborns and to identify antenatal predictors of LGA.

STUDY DESIGN: This cross-sectional study included 536 term, singleton infants. Anthropometric measurements were performed within 48 h of birth and included determination of body fat percentage (%BF) by air displacement plethysmography. Associations were investigated using logistic regression.

RESULT: LGA infants had greater %BF ($P < 0.001$) compared with AGA infants. Significant predictors of LGA infants included parity (odds ratio (OR) = 1.98, (95% confidence interval (CI) 1.00, 4.02)), paternal height (OR = 1.08, (95% CI 1.03, 1.14)), maternal pregravid weight (65 to 74.9 kg: OR = 2.77, (95% CI 1.14, 7.06)) and gestational weight gain (OR = 1.09, 95% CI (1.03, 1.16)). Gestational diabetes mellitus was not associated with LGA infants ($P = 0.598$).

CONCLUSION: Paternal height, parity, maternal pregravid weight and gestational weight gain were strongly associated with LGA infants. These results may allow early prediction and potential modification, thereby optimising clinical outcomes.

Journal of Perinatology (2014) **34,** 698–704; doi:10.1038/jp.2014.90; published online 15 May 2014

INTRODUCTION

The increasing worldwide prevalence of obesity is a major challenge of our time.[1] There is strong evidence for the association between maternal obesity and high infant birthweight.[2–5] Therefore, an increase in the prevalence of large-for-gestational-age (LGA) infants is likely, considering the increasing prevalence of obesity.[1,6] LGA infants are at increased risk of both short- and long-term poor outcomes, such as adult obesity and metabolic disease.[7–10] However, not all LGA infants are at increased risk of morbidity. Differentiating between constitutionally large infants and overgrown infants is important but has previously been difficult to determine. Measuring infant body composition may be the answer.

Infant body composition has been shown to affect longer-term health outcomes[11] and is a better measure of infant nutritional status than birthweight, as it is more sensitive to factors affecting infant growth *in utero*.[12–15]

Until recently, accurately assessing infant body composition was difficult. However, it is now possible in routine clinical practice using air displacement plethysmography (ADP). This method has been validated[16,17] and is the gold standard for measuring infant body composition.[18–22]

In this study, we performed anthropometric measurements and determined body composition of LGA infants using ADP. We also aimed to identify antenatal predictors and short-term labour and birth outcomes associated with LGA infants.

METHODS

Study design

In this cross-sectional study, we recruited infants born at Royal Prince Alfred Hospital (RPAH) in Sydney from August to October 2010. Eligible patients were well, term newborns measured once, within 48 h of birth. Exclusion criteria included gestational age < 37 or $\geqslant 42$ weeks, multiple births, congenital anomalies and neonatal intensive care unit admission for >2 days.

Data collection

Body composition and other anthropometric measurements in neonates. All neonatal measurements were performed within 48 h of birth. Weight and body composition were measured by ADP, using the PEA POD Infant Body Composition System (COSMED, Chicago, IL, USA) with integrated software (version 3.1.3). Before measuring, all clothing was removed, and the hair was smoothed to reduce its isothermic behaviour. Mass and volume calibrations accounted for the two hospital identification bracelets and umbilical clip on each infant. Weight was measured using the integrated scale.

Body composition measured by ADP was then calculated from body density based on the model presented by Fomon.[23] The density of fat was assumed to be 0.9007 kg l^{-1}. The data were reported based on a two-compartment model of fat mass and fat-free mass. Fat mass was also provided as a percentage of total body weight, body fat percentage (%BF).

The method for performing all other measurements was standardised using the skill-based educational methods.[24] An experienced neonatologist assessed competency (HEJ). Inter-user reliability was established before starting the study. Crown-heel length was measured by two operators using an Easy-Glide Bearing Infantometer (Perspective Enterprises, Portage, MI, USA). Head circumference was recorded as the maximal occipitofrontal circumference of three measurements. Chest, abdominal, arm and thigh circumference were measured at the level of the nipples and umbilicus, mid-humeral and mid-femoral points, respectively. Two measurements were made for each, and the mean was recorded. All measurements were made with a circumferential, re-useable plastic tape-measure (Perspective Enterprises).

Parental anthropometric, demographic, pregnancy and medical data. Data were obtained through interview with either parent at the time of the

[1]Sydney Medical School, University of Sydney, Sydney, NSW, Australia; [2]Sydney School of Public Health, University of Sydney, Sydney, NSW, Australia and [3]RPA Newborn Care, Royal Prince Alfred Hospital, Sydney, NSW, Australia. Correspondence: Dr EL Donnelley, Sydney Medical School, University of Sydney, Edward Ford Building, Fisher Road, Camperdown, NSW 2006, Australia.
E-mail: erin.donnelley@gmail.com
Received 16 November 2013; revised 27 March 2014; accepted 27 March 2014; published online 15 May 2014

infant measurements using a standardised questionnaire or were extracted from the medical records. Maternal data included age, height, pregravid weight, gestational weight gain, ethnicity, parity, antenatal history, details of the labour and delivery and length of stay in hospital. Paternal data included age, height and weight. Infant data included sex, gestational age, any fetal distress, Apgar scores, temperature, blood glucose concentration, admissions to the neonatal intensive care unit and initial feeding scores.

'Gestational age' was calculated from the first day of the last menstrual period according to Naegele's rule. This date was adjusted to the first or second trimester ultrasound scan estimation if the estimates differed by >7 days. Body mass index (BMI) was calculated by dividing weight (kg) by the height squared (m^2). The World Health Organisation BMI classification was applied.[1] 'Ethnicity' was defined according to the Australian Standard Classification of Cultural and Ethnic Groups.[25]

The diagnosis of gestational diabetes mellitus (GDM) was based on the Australian Diabetes in Pregnancy Society criteria, including universal screening at 26 to 28 weeks of gestation by 50 or 75 g oral glucose challenge test.[26] The diagnosis was confirmed by a 75-g oral glucose tolerance test. A positive result included a venous blood glucose concentration of $\geqslant 5.5$ mmol l^{-1} after fasting or of $\geqslant 8.0$ mmol l^{-1} 2 h after a 75-g glucose load. Where the oral glucose tolerance test had been performed, the new international recommendation from the International Association of Diabetes and Pregnancy Study Group was applied *post hoc*. A positive result included a venous blood glucose concentration of $\geqslant 5.1$ mmol l^{-1} after fasting, $\geqslant 10.0$ mmol l^{-1} after 1 h or $\geqslant 8.5$ mmol l^{-1} after 2 h.[27]

Labour and birth outcomes

Infants were classified by weight for gestational age and sex using population-based charts.[28] Small for gestational age was defined as $<$ 10th percentile, appropriate for gestational age (AGA) as $\geqslant$ 10th and $\leqslant$ 90th percentile and LGA as >90th percentile weight for gestational age. Small-for-gestational-age infants were excluded from all analyses.

Low %BF LGA neonates were excluded from the subgroup analysis. The cutoff points for low and high %BF have not been previously identified.[12] Therefore 'high fat' and 'low fat' were defined as 1 s.d. above and below the mean %BF.[29]

We used objective measures to identify infants at risk of early morbidity.[30] 'Fetal distress' was defined as either an indication for operative delivery or thick meconium at birth from the medical record. 'Low Apgar score' was defined as an Apgar score <7 at 5 min and/or a requirement for resuscitation at birth. 'Hypothermia' was defined by a temperature of $<36.5\,^{o}$C recorded at birth or at any time during admission. 'Hypoglycaemia' was defined as blood glucose concentration <2 mmol in the first 24 h and <2.5 mmol after the first 24 h, measured either by screening blood glucose concentration (glucometer at the bedside, Accu-Chek, Roche Diagnostics, Indianapolis, IN, USA) and/or confirmed by formal blood glucose concentration (hospital laboratory service).[31] Blood glucose was not measured routinely in LGA infants. 'Breast-feeding morbidity' was defined as $\geqslant 2$ of the following criteria: (i) poor feeding frequency defined by <3 feeds in the first 24 h and/or <6 feeds in the subsequent 24 h, (ii) poor feeding codes defined as >3 codes of $<4/6$ as assessed by midwives according to hospital feeding codes, and (iii) poor feeding requiring >2 supplementary feeds with either expressed breast milk or formula.[29]

Statistical analysis

Descriptive statistics were calculated using the mean and s.d. for continuous variables and number (%) for categorical variables. Univariate associations between variables were calculated using chi-square and *t*-tests as appropriate. Associations between LGA and antenatal risk factors were assessed using the logistic regression models and a multivariable model using stepwise backwards elimination. All analyses were conducted in 'R for Mac OS X GUI 1.43'.[32]

Ethics

The Human Research Ethics Committees of RPAH (X09-0381 HREC/09/RPAH/645) and the University of Sydney (12732) approved this study. All parents gave informed written consent, and participation was voluntary.

RESULTS

A total of 475 (88.6%) AGA and 61 (11.4%) LGA neonates were included. The two groups of infants were not significantly different in terms of sex or gestational age, and the two groups of mothers were not significantly different in their age or ethnicity (Table 1).

Comparison of LGA and AGA neonates—antenatal predictors, neonatal anthropometry and labour and birth outcomes

Antenatal predictors. Several factors were significantly associated with parental anthropometric features and LGA compared with AGA neonates (Table 1), including multiparity, paternal height, maternal gestational weight gain and pregravid weight. In the multivariable model, significant predictors of LGA infants included multiparity ($P = 0.043$), paternal height ($P = 0.002$), maternal gestational weight gain ($P = 0.001$) and pregravid weight ($P < 0.001$) (Table 2). For women with a pregravid weight of 65 to 75 kg, there were increased odds of having an LGA infant, compared with women with a pregravid weight of 55 to 65 kg (odds ratio (OR) = 2.77, 95% confidence interval (CI) (1.14 to 7.06) and even higher odds for women with a pregravid weight of $\geqslant$ 75 kg (OR = 6.37, 95% CI (2.53 to 16.92).

The probability of having an LGA infant estimated from the multivariable model is shown for varying combinations of antenatal factors in Figure 1. The estimated probability of having an LGA infant increased with the maternal gestational weight gain, taller paternal height (Figure 1a), pregravid weight (Figure 1b) and parity (Figure 1c).

Neither maternal GDM status nor type 2 diabetes mellitus was associated with having an LGA infant. Applying the new international criteria *post hoc* to the oral glucose tolerance test results found no further GDM diagnoses.[27]

Neonatal anthropometry. The LGA neonates had significantly different anthropometry to AGA neonates (Table 3). On average, they had a higher percentage body fat, greater BMI, were longer and had a greater head, chest, abdominal, arm and thigh circumference ($P < 0.001$). There was a proportional increase in the body fat of LGA compared with AGA infants. However, the distribution of %BF in LGA infants, while higher on average, did not have a substantially higher maximum %BF (Figure 2).

Labour and birth outcomes. Overall, LGA neonates did not have a significantly different risk of adverse labour or birth outcomes compared with AGA neonates. However, they were more likely to be delivered by caesarean section (C/S) and more than twice as likely to be delivered by elective C/S, compared with AGA neonates ($P = 0.003$; Table 4). There was no difference in the rate of induction (23.0% for LGA neonates compared with 23.8% for AGA neonates) or fetal distress. There were no 'hypoglycaemic' episodes recorded for any of these infants at any point.

Sub-group analysis of LGA neonates with high %BF compared with LGA neonates with normal %BF

Of the 61 LGA neonates, 32 had a high %BF and 28 had a normal %BF. There was a single LGA neonate with low %BF (5.6%) who was identified with lymphocytic villitis on the placental pathology report. The neonates in the high %BF group and normal %BF group were not significantly different in terms of neonatal sex or gestation.

Antenatal predictors. The only parental characteristics associated the 32 infants with high %BF in LGA infants were shorter maternal height and Asian ethnicity (Table 5). Other anthropometric and demographic factors did not predict for %BF in LGA infants, including parental age, height, weight or BMI, parity, GDM or type 2 diabetes mellitus status.

Table 1. Characteristics of large-for-gestational-age neonates compared with appropriate-for-gestational-age neonates

Characteristics	*LGA (n = 61)*	*AGA (n = 475)*		
	Mean ± s.d. or n (%)	*Mean ± s.d. or n (%)*	*Mean difference (LCL, UCL)*	P-*value*
Maternal characteristics				
Age (years)	33.6 ± 6.1	32.6 ± 5.1	1.0 (−0.6, 2.6)	0.230
Ethnicity				0.535
Caucasian	40 (65.6%)	291 (61.3%)		
Asian	16 (26.2%)	159 (33.5%)		
Other	4 (6.6%)	22 (4.6%)		
Missing data	1 (1.6%)	3 (0.6%)		
Diabetes mellitus				
GDM	5 (8.2%)	54 (11.4%)		0.598
T1DM	0 (0.0%)	0 (0.0%)		
T2DM	1 (1.6%)	2 (0.4%)		0.306
Parity				0.062
Primiparous	26 (42.6%)	267 (56.2%)		
Multiparous	35 (57.4%)	208 (43.8%)		
Height (m)	1.67 ± 0.07	1.63 ± 0.07	0.04 (0.02, 0.06)	< 0.001
Pregravid weight (kg)	69.0 ± 12.2	62.1 ± 12.6	6.9 (3.5, 10.3)	< 0.001
Pregravid body mass index (kg m^{-2})	24.6 ± 4.1	23.1 ± 4.1	1.5 (0.3, 2.6)	0.013
Underweight (< 18.5)	6 (9.8%)	90 (18.9%)		
Normal (18.5–24.9)	26 (42.6%)	254 (53.9%)		
Overweight (25–29.9)	20 (32.8%)	75 (15.8%)		
Obese (⩾30)	4 (6.6%)	33 (6.9%)		
Missing data	5 (8.2%)	23 (4.8%)		
Gestational weight gain (kg)	14.8 ± 6.1	12.6 ± 8.0	2.2 (0.2, 4.1)	0.030
Paternal characteristics				
Age (years)	35.2 ± 6.6	35.0 ± 6.1	0.2 (−1.7, 2.0)	0.845
Height (m)	1.81 ± 0.06	1.77 ± 0.11	0.03 (0.01, 0.06)	0.002
Weight (kg)	89.6 ± 17.7	82.5 ± 13.7	7.2 (2.1, 12.2)	0.007
Body mass index (kg m^{-2})	27.6 ± 5.4	26.2 ± 3.7	1.4 (−0.1, 3.0)	0.069
Underweight (< 18.5)	0 (0.0%)	7 (1.5%)		
Normal (18.5–24.9)	19 (31.1%)	154 (32.4%)		
Overweight (25–29.9)	21 (34.4%)	180 (37.9%)		
Obese (⩾30)	11 (18.0%)	60 (12.6%)		
Missing data	10 (16.4%)	74 (15.6%)		
Neonatal characteristics				
Sex				0.367
Male	35 (57.4%)	239 (50.3%)		
Female	26 (42.6%)	236 (49.7%)		
Gestational age (weeks)	39.6 ± 1.1	39.5 ± 1.1	0.1 (−0.2, 0.4)	0.595

Abbreviations: AGA, appropriate for gestational age; GDM, gestational diabetes mellitus; LCL, lower control limit; LGA, large for gestational age; T1DM, type 1 diabetes mellitus; T2DM, type 2 diabetes mellitus; UCL, upper control limit.

Neonatal anthropometry. Statistically significant anthropometric differences between LGA neonates with high and normal fat included abdominal circumference with high fat neonates having a 1.1-cm greater circumference on average (95% CI: 0.1 × 2.0), thigh circumference with high fat neonates having a 1-cm greater circumference on average (95% CI: 0.5 × 1.6) and BMI with high % BF neonates having a 0.8 kg m^{-2} greater BMI on average (95% CI: 0.3 × 1.3).

Labour and birth outcomes. High-fat LGA neonates were at a significantly decreased risk of fetal distress during labour compared with normal-fat LGA neonates ($P = 0.03$). There was weak evidence that mode of delivery differed for high- and normal-fat neonates ($P = 0.08$). More than twice as many high-fat neonates were delivered by elective C/S (13 (40.6%) high-fat infants compared with 5 (15.9%) normal-fat infants). Three times more normal-fat infants than high-fat infants required either instrumental delivery or emergency C/S (11 (39.3%) normal-fat infants compared with 4 (12.6%) high-fat infants).

DISCUSSION

Main findings

LGA is associated with childhood obesity and metabolic dysfunction in adulthood and is a significant public health issue in low-, medium- and high-income settings. In this study, we have found

Table 2. Antenatal predictors of large-for-gestational-age neonates compared with appropriate-for-gestational-age neonates

Antenatal predictors	*Univariate*		*Multivariable*	
	Odds ratio (LCL, UCL)	P-*value*	*Odds ratio (LCL, UCL)*	P-*value*
Predictors included in the multivariable model				
Parity	1.73 (1.01, 2.99)	0.045	1.98 (1.00, 4.02)	0.043
Paternal height (cm)	1.07 (1.02, 1.12)	0.002	1.08 (1.03, 1.14)	0.002
Maternal gestational weight gain (kg)	1.05 (1.00, 1.11)	0.034	1.09 (1.03, 1.16)	0.001
Maternal pregravid weight (kg)		<0.001		<0.001
<50	1.00 (0.22, 3.27)		1.88 (0.39, 7.02)	
50–54.9	0.81 (0.22, 2.36)		0.78 (0.16, 2.82)	
55–64.9 (reference category)	1.00		1.00	
65–74.9	2.54 (1.21, 5.50)		2.77 (1.14, 7.06)	
$\geqslant 75$	5.58 (2.61, 12.32)		6.37 (2.53, 16.92)	
Other predictors[a]				
Maternal height (cm)	1.09 (1.05, 1.14)	<0.001		
Maternal body mass index (kg m^{-2})		0.010		
Underweight (<18.5)	0.65 (0.24, 1.54)			
Normal (18.5–24.9) (reference category)	1.00			
Overweight (25–29.9)	2.61 (1.37, 4.92)			
Obese ($\geqslant 30$)	1.18 (0.33, 3.28)			
Paternal weight (kg)		0.108		
<65	0.38 (0.02, 2.04)			
65–74.9	0.54 (0.19, 1.37)			
75–84.9 (reference category)	1.00			
85–94.9	1.34 (0.62, 2.90)			
$\geqslant 95$	1.66 (0.76, 3.61)			
Paternal body mass index (kg m^{-2})		0.533		
Normal (18.5–24.9) (reference category)	1.00			
Overweight (25–29.9)	0.93 (0.40, 2.00)			
Obese ($\geqslant 30$)	1.46 (0.54, 3.47)			

Abbreviations: LCL, lower control limit; UCL, upper control limit.
[a]This multivariable model was based on the 404 neonates with complete covariate information.

that paternal height, parity, pregravid weight and gestational weight gain are strongly associated with LGA infants. Further, these infants had a higher proportion of body fat than the AGA infants in the population.

We described, for the first time, the body composition of LGA neonates within the first 48 h of life using ADP. The LGA infants were found to have a significantly greater %BF compared with AGA infants, and their increase in fat mass was proportionally greater than their increase in body weight. They were symmetrically larger than the AGA infants on all anthropometric dimensions. These findings were in keeping with Anderson *et al*.,[22] who demonstrated using ADP that infants with higher birthweight had higher body fat at 3 months of age.

The association between maternal GDM status and LGA infants is well established.[33,34] However, in our study maternal GDM status did not predict LGA infants nor high %BF.[35] This may be attributed to the tight glycaemic control previously reported in our maternal population mitigating the effects of maternal hyperglycaemia on the fetus.[35] By applying the new international criteria to our population, we ensured this result was not an artefact of less stringent diagnostic criteria. We recognise that achieving similar levels of maternal adherence with strict guidelines may only be possible in centres with sufficient resources. However, this confirms that GDM status is indeed a modifiable risk factor for LGA infants. Although GDM status was not associated with LGA in our population, it is possible that other metabolic factors are associated with LGA infants.[36,37]

This study therefore describes a population of LGA infants, which cannot be attributed to maternal GDM. This may indicate normal, healthy growth in a LGA group and is reflected in the relatively low clinical morbidity of these infants. There were also no differences in morbidity outcomes when compared with the AGA group, other than an increased rate of caesarean section delivery. It is not known whether these 'non-GDM' LGA infants have the same risk of childhood obesity.

The generalisability of the study is limited to an extent by the high-resource setting and that a low cost and sensitive surrogate marker for %BF is yet to be identified. A larger sample of infants with longer-term follow-up is needed to provide insight into the impact of body composition at birth and optimal early intervention to reduce the risk of childhood and adult obesity. However, this was a prospective, cross-sectional study design and used the gold standard method of ADP to measure infant body composition.

These findings highlight the importance of maternal weight in predicting LGA infants independent of GDM status. There are immediate clinical implications in terms of modifying maternal pregravid weight and pregnancy weight gain, especially in the context of a multiparous mother and tall father. Successfully addressing modifiable perinatal factors may achieve both a decrease in caesarean delivery and, in the longer term, a decrease in child and adult overweight and obesity.

All risk factors for predicting proportional body fat have not been clearly elucidated. We found shorter maternal height and

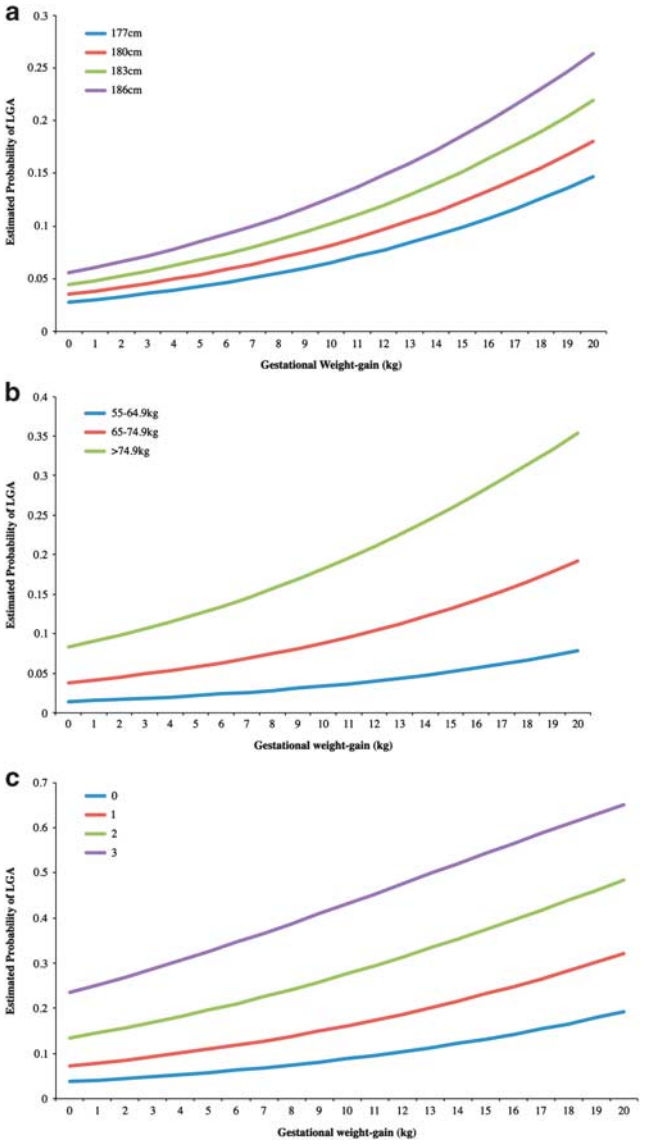

Figure 1. (**a**) Estimated probability of delivering a large-for-gestational-age (LGA) neonate by gestational weight gain and paternal height. (**b**) Estaimated probability of delivering a LGA neonate by gestational weight gain and maternal pregravid weight. (**c**) Estimated probability of delivering a LGA neonate by gestational weight gain and parity.

Asian ethnicity to predict high %BF in LGA infants. This is provocative, as GDM was not explanatory in the regression model. The fetal programming hypothesis may offer one explanation and, as in our study, short maternal height has previously been

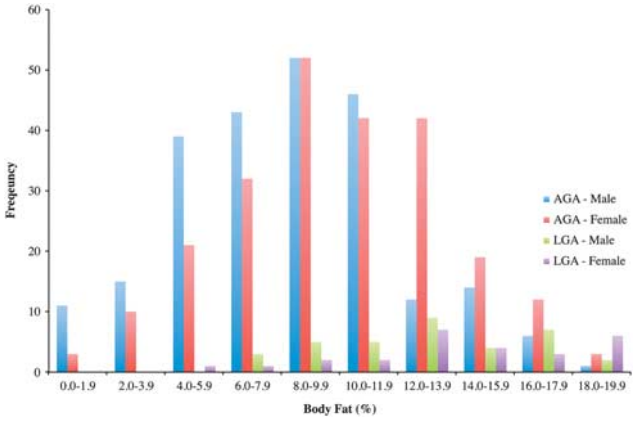

Figure 2. Frequency distribution of percentage body fat. AGA, appropriate for gestational age; LGA, large for gestational age.

Table 4. Labour and birth outcomes for large-for-gestational-age neonates compared with appropriate-for-gestational-age neonates

Outcomes	*LGA* (n = *61*)	*AGA* (n = *475*)	
	n *(%)*	n *(%)*	P-*value*
Onset of labour			0.07
Spontaneous	32 (52.5%)	297 (62.5%)	
Induction	14 (23.0%)	113 (23.8%)	
No labour	15 (24.6%)	65 (13.7%)	
Fetal distress			0.34
Fetal distress	17 (27.9%)	166 (34.9%)	
No fetal distress	44 (72.1%)	309 (65.1%)	
Delivery			0.003
Normal vaginal	28 (45.9%)	265 (55.8%)	
Instrumental	8 (13.1%)	81 (17.1%)	
Emergency C/S	7 (11.5%)	72 (15.2%)	
Elective C/S	18 (29.5%)	57 (12.0%)	

Abbreviations: AGA, appropriate for gestational age; C/S, Caesarean section; LGA, large for gestational age.

Table 3. Neonatal anthropometry for large-for-gestational-age neonates compared with appropriate-for-gestational-age neonates

Anthropometry	*LGA* (n = *61*)	*AGA* (n = *475*)	
	Mean ± s.d.	*Mean ± s.d.*	*Mean difference (LCL, UCL)*
Body fat (%)	13.6 ± 3.8	9.2 ± 3.9	4.5 (3.4, 5.5)***
Length (cm)	52.2 ± 1.8	49.7 ± 1.6	2.5 (2.0, 3.0)***
Body mass index (kg m^{-2})	15.6 ± 1.0	13.8 ± 1.2	1.8 (1.5, 2.1)***
Head circumference (cm)	35.9 ± 1.1	34.5 ± 1.0	1.5 (1.2, 1.7)***
Chest circumference (cm)	35.0 ± 1.4	32.5 ± 1.3	2.5 (2.1, 2.9)***
Abdominal circumference (cm)	33.4 ± 1.8	30.4 ± 1.7	3.0 (2.5, 3.5)***
Arm circumference (cm)	12.2 ± 0.9	10.8 ± 0.8	1.4 (1.1, 1.6)***
Thigh circumference (cm)	16.8 ± 1.2	15.0 ± 1.1	1.8 (1.5, 2.2)***

Abbreviations: AGA, appropriate for gestational age; LCL, lower control limit; LGA, large for gestational age; UCL, upper control limit.
***$P < 0.001$.

Table 5. Characteristics of large-for-gestational-age neonates with high body fat (%) compared with large-for-gestational-age neonates with normal body fat (%)

Maternal characteristics	*High %BF (n = 32)*	*Normal %BF (n = 28)*		
	Mean ± s.d. or n *(%)*	*Mean ± s.d. or* n *(%)*	*Mean difference (LCL, UCL)*	P-*value*
Age (years)	33.5 ± 6.2	34.1 ± 5.7	0.5 (−2.5, 3.6)	0.726
Ethnicity				0.020
Caucasian	17 (53.1%)	23 (82.1%)		
Asian	12 (37.5%)	4 (14.3%)		
Other	3 (9.4%)	0 (0.0%)		
Missing Data	0 (0.0%)	1 (3.6%)		
Diabetes mellitus				0.830
GDM	3 (9.4%)	2 (7.1%)		
T2DM	0 (0.0%)	1 (3.6%)		
Parity				0.848
Primiparous	13 (40.6%)	13 (46.4%)		
Multiparous	19 (59.4%)	15 (53.6%)		

Abbreviations: BF, body fat; GDM, gestational diabetes mellitus; LCL, lower control limit; T2DM, type 2 diabetes mellitus; UCL, upper control limit.

associated with neonatal adiposity in an Indian population,[38] and Asian ethnicity has also been shown to predict adiposity.[39] The predictors of neonatal adiposity will require further investigation in larger studies.

It is possible that the relative increase in %BF of LGA infants reflects a metabolic pattern that may contribute to childhood regulation of metabolism and long-term risk of obesity. The relative contribution of *in utero* and postnatal environment to childhood metabolism and long-term risk of obesity is currently unclear. Eriksson *et al*.[20] found body fat was not correlated in infants at 1 and 12 weeks of age, and Wells *et al*.[40] found that postnatal weight gain had a stronger influence than fetal weight gain on fat distribution. Neither study controlled for maternal GDM status.

In this population study, predictors of LGA were identified as paternal height, parity, maternal pregravid weight and gestational weight gain. Further, the LGA neonates were not only larger but also fatter than AGA infants, a finding not attributable to maternal GDM status. Future research might address the impact of antenatal education on modifying LGA newborns and the collateral health implications.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank the RPAH midwifery and neonatal staff, as well as mothers and babies who participated in the study. Thank you to Cheryl Au, Elizabeth Hales, Meredith Li and Lucia Wang for their assistance with data collection.

Funding: The PEA POD was funded by Tenix Pty Ltd and an anonymous donor from the Faculty of Medicine at the University of Sydney. CHR-G, at the time of this work, was supported by an Australian National Health and Medical Research Council (NHMRC) Early Career Fellowship no. 511481. RMT is supported by NHMRC grant no. 633003 to the Screening and Test Evaluation Program. AEC, at the time of this work, was supported by an Australia Postgraduate PhD award.

AUTHOR CONTRIBUTIONS

ELD contributed to the study design and data collection, analysed the data and wrote the manuscript. HEJ designed the study, supervised data collection, contributed to data analysis, interpretation and discussion, as well as reviewed and edited the manuscript. CHR-G contributed to study design, data interpretation, reviewed and edited the manuscript. RMT provided statistical advice and reviewed and edited the manuscript. AEC assisted with data design and supervised the data collection. All authors have reviewed the paper and agreed to its content.

REFERENCES

1 World Health Organisation. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser* 2000; **894** (i-xii): 1–253.
2 Ay L, Kruithof CJ, Bakker R, Steegers EAP, Witteman JCM, Moll HA *et al.* Maternal anthropometrics are associated with fetal size in different periods of pregnancy and at birth. The Generation R Study. *BJOG* 2009; **116**(7): 953–963.
3 Khashan AS, Kenny LC. The effects of maternal body mass index on pregnancy outcome. *Eur J Epidemiol* 2009; **24**(11): 697–705.
4 Siega-Riz AM, Viswanathan M, Moos M-K, Deierlein A, Mumford S, Knaack J *et al.* A systematic review of outcomes of maternal weight gain according to the Institute of Medicine recommendations: birthweight, fetal growth, and postpartum weight retention. *Am J Obstet Gynecol* 2009; **2014**(339): e1-14.
5 Ng S-K, Olog A, Spinks AB, Cameron CM, Searle J, McClure RJ. Risk factors and obstetric complications of large for gestational age births with adjustments for community effects: results from a new cohort study. *BMC Public Health* 2010; **10**: 460.
6 Booth M, Chey T, Wake M, Norton K, Hesketh K, Dollman J *et al.* Change in the prevalence of overweight and obesity among young Australians, 1969-1997. *Am J Clin Nutr* 2003; **77**: 29–36.
7 Mehta SH, Kruger M, Sokol RJ. Being too large for gestational age precedes childhood obesity in African Americans. *Am J Obstet Gynecol* 2011; **204**(3): 265 e1–e5.
8 Rogers I. Group E-BS. The influence of birthweight and intrauterine environment on adiposity and fat distribution in later life. *Int J Obes Relat Metab Disord* 2003; **27** (7): 755–777.
9 Oken E, Gillman MW. Fetal origins of obesity. *Obes Res* 2003; **11**(4): 496–506.
10 Ismail-Beigi F, Catalano PM, Hanson RW. Metabolic programming: fetal origins of obesity and metabolic syndrome in the adult. *Am J Physiol Endocrinol Metab.* 2006; **291**(3): E439–E440.
11 Yajnik CS. The lifecycle effects of nutrition and body size on adult adiposity, diabetes and cardiovascular disease. *Obes Rev* 2002; **3**(3): 217–224.
12 Schmelzle HR, Quang DN, Fusch G, Fusch C. Birth weight categorization according to gestational age does not reflect percentage body fat in term and preterm newborns. *Eur J Pediatr* 2007; **166**(2): 161–167.
13 Catalano PM, Thomas A, Huston-Presley L, Amini SB. Increased fetal adiposity: a very sensitive marker of abnormal in utero development. *Am J Obstet Gynecol* 2003; **189**(6): 1698–1704.
14 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 Relat Metab Disord* 2003; **27**(2): 173–180.
15 Beattie RB, Johnson P. Practical assessment of neonatal nutrition status beyond birthweight: an imperative for the 1990s. *BJOG* 1994; **101**(10): 842–846.
16 Ellis KJ, Yao M, Shypailo RJ, Urlando A, Wong WW, Heird WC. Body-composition assessment in infancy: air-displacement plethysmography compared with a reference 4-compartment model. *Am J Clin Nutr* 2007; **85**(1): 90–95.
17 Urlando A, Dempster P, Aitkens S. A new air displacement plethysmograph for the measurement of body composition in infants. *Pediatr Res* 2003; **53**(3): 486–492.
18 Lingwood BE, Henry AM, d'Emden MC, Fullerton A-M, Mortimer RH, Colditz PB *et al.* Determinants of body fat in infants of women with gestational diabetes mellitus differ with fetal sex. *Diabetes Care* 2011; **34**(12): 2581–2585.
19 Hawkes CP, Hourihane JOB, Kenny LC, Irvine AD, Kiely M, Murray DM. Gender- and Gestational Age–Specific Body Fat Percentage at Birth. *Pediatrics* 2011; **128**(3): e645–e651.
20 Eriksson B, Lof M, Forsum E. Body composition in full-term healthy infants measured with air displacement plethysmography at 1 and 12 weeks of age. *Acta Paediatr* 2010; **99**(4): 563–568.
21 Carberry AE, Colditz PB, Lingwood BE. Body composition from birth to 4.5 months in infants born to non-obese women. *Pediatr Res* 2010; **68**(1): 84–88.
22 Anderson AK, McDougald DM, Steiner-Asiedu M. Dietary trans fatty acid intake and maternal and infant adiposity. *Eur J Clin Nutr* 2010; **64**(11): 1308–1315.
23 Fomon SJ, Haschke F, Ziegler EE, Nelson SE. Body composition of reference children from birth to age 10 years. *Am J Clin Nutr* 1982; **35**(5 Suppl): 1169–1175.

24 Hill D.A. SCORPIO: a system of medical teaching, medical teacher. *Med Teach* 1992; **14**(1): 37–41.
25 Statistics. ABo. Australian Standard Classification of Cultural and Ethnic Groups (ASCCEG), 2nd edn, 2005. http://www.abs.gov.au/ausstats/abs@.nsf/latestproducts/1249.0Main%20Features22011?opendocument&tabname=Summary&prodno=1249.0&issue=2011&num=&view=
26 Hoffman L, Nolan C, Wilson JD, Oats JJ, Simmons D. Gestational diabetes mellitus-management guidelines. The Australasian Diabetes in Pregnancy Society. *Med J Aust* 1998; **169**(2): 93–97.
27 Metzger BE, Gabbe SG, Persson B, Buchanan TA, Catalano PA, Damm P *et al.* International Association of Diabetes and Pregnancy Study Groups Consensus Panel. International association of diabetes and pregnancy study groups recommendations on the diagnosis and classification of hyperglycemia in pregnancy. *Diabetes Care* 2010; **33**(3)):676–682.
28 Beeby PJ, Bhutap T, Taylor LK. New South Wales population-based birthweight percentile charts. *J Paediatr Child Health* 1996; **32**(6): 512–518.
29 Carberry AE, Turner RM, Askie LM, Jeffery HE. Is body fat percentage a better measure of undernutrition in newborns than birth weight percentiles? *Pediatr Res* 2013; **74**: 730–736.
30 Zhang X, Decker A, Platt RW, Kramer MS. How big is too big? The perinatal consequences of fetal macrosomia. *Am J Obstet Gynecol* 2008; **198**5: 517 e1–e6.
31 Royal Prince Alfred Hospital, Sydney. *Newborn Care Guidelines*. Evans N (ed). 2013. Sydney, Australia (http://www.sswahs.nsw.gov.au/rpa/neonatal/protocols.html)
32 Team RDC. *R: A Language and Environment for Statistical Computing* . R Foundation for Statistical Computing: Vienna, Austria, 2010.
33 Ehrenberg HM, Mercer BM, Catalano PM. The influence of obesity and diabetes on the prevalence of macrosomia. *Am J Obstet Gynecol* 2004; **191**(3): 964–968.
34 Schaefer-Graf UM, Kjos SL, Kilavuz O, Plagemann A, Brauer M, Dudenhausen JW *et al.* Determinants of fetal growth at different periods of pregnancies complicated by gestational diabetes mellitus or impaired glucose tolerance.[Erratum appears in Diabetes Care. 2003;26(4):1329]. *Diabetes Care* 2003; **26**(1): 193–198.
35 Au CP, Raynes-Greenow CH, Turner RM, Carberry AE, Jeffery HE. Body composition is normal in term infants born to mothers with well-controlled gestational diabetes mellitus. *Diabetes Care* 2013; **36**(3): 562–564.
36 Evagelidou EN, Giapros VI, Challa AS, Cholevas VK, Vartholomatos GA, Siomou EC *et al.* Prothrombotic state, cardiovascular, and metabolic syndrome risk factors in prepubertal children born large for gestational age. *Diabetes Care* 2010; **33**(11): 2468–2470.
37 Harmon KA, Gerard L, Jensen DR, Kealey EH, Hernandez TL, Reece MS *et al.* Continuous glucose profiles in obese and normal-weight pregnant women on a controlled diet: metabolic determinants of fetal growth. *Diabetes Care* 2011; **34**(10): 2198–2204.
38 Yajnik CS, Deshmukh US. Maternal nutrition, intrauterine programming and consequential risks in the offspring. *Rev Endocr Metab Disord* 2008; **9**(3): 203–211.
39 Wells JCK. Commentary: Why are South Asians susceptible to central obesity?—the El Nino hypothesis. *Int J Epidemiol* 2007; **36**(1): 226–227.
40 Wells JCK, Haroun D, Levene D, Darch T, Williams JE, Fewtrell MS. Prenatal and postnatal programming of body composition in obese children and adolescents: evidence from anthropometry, DXA and the 4-component model. *Int J Obes (Lond)* 2011; **35**(4): 534–534.