Original Article

Fetal growth and birth size is associated with maternal anthropometry and body composition

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Abstract

The objective was to investigate the association of maternal weight, height and body composition with fetal growth. We recruited 425 women at the University Hospital of the West Indies, Jamaica, who had singleton pregnancies, were less than 15 weeks gestation and had no systemic illness. Maternal weight, height and skinfold thicknesses were measured at the first antenatal visit and lean mass was calculated. Sonographic measurements of the fetus were made at 15, 25 and 35 weeks gestation. Weight, crown-heel length and head circumference were measured at birth. Analyses were confined to 360 (85%) women; 65 women did not complete the study. Maternal height was positively associated with femoral length at 25 and 35 weeks gestation and with head circumference at 35 weeks (all $P < 0.02$). Maternal weight was positively associated with abdominal circumference and femoral length at 25 weeks, and with larger head and abdominal circumference and longer femur at 35 weeks (all $P < 0.02$). Maternal lean mass had similar associations to maternal weight and they were both positively associated with estimated fetal weight (all $P < 0.02$). All three maternal measurements were positively associated with birthweight, length and head circumference. Maternal size was associated with fetal size as early as 25 weeks gestation, with height strongly associated with femoral length, and with weight and lean mass strongly associated with abdominal circumference.

Keywords: fetal growth, maternal anthropometry, body composition.

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Introduction

It is well known that maternal pre-pregnancy anthropometry influences birth size (Kramer 1987; Thame *et al.* 1997). Ideally pre-pregnancy weight should be recorded. However, several studies have used maternal measurements in the first trimester as a proxy for pre-pregnancy weight (Gueri *et al.* 1982). Birth size is important as it is associated with perinatal and neonatal mortality and morbidity (McCormick 1985; Brundtland 2002). Low-birthweight and

small-for-gestational-age infants may be a result of intrauterine growth restriction and a compromised maternal nutritional status (de Onis *et al.* 1998). These infants are at increased risk for developing complications which may be life threatening. In Latin America and the Caribbean, the prevalence of small for gestational age is approximately 6.6%, and in Jamaica, it is about 4–5% (de Onis 2000). These rates are much lower than in Asia (12.2%). In India, the rate is 33% – the second highest in the world (Dilip 2002).

The importance of studying size at birth is further suggested by evidence that it is associated with chronic disease in adult life (Barker *et al.* 1992; Law & Shiell 1996; Barker 1997).

There is extensive literature to support the influence of maternal size on birthweight, but there have been few studies that have investigated the relationship between maternal size and fetal growth. Thame *et al.* 2004 and Ay *et al.* 2009 both reported that fetal size was positively associated with maternal size, especially maternal gestational weight gain.

An infant's weight in post-natal life normally tracks along centile curves. It appears that fetal weight may also track *in utero*. It is well established that maternal weight and height are associated with birth size and we postulate that there is also a direct effect of maternal weight, height and body composition on fetal size. This effect of maternal nutritional status on fetal growth may not be evident in all trimesters of pregnancy, but it is possible that, as the fetus becomes older, such an association may emerge. The identification *in utero* of when this association occurs may be useful for the obstetrician, who could then identify and increase surveillance of the fetus at risk. Early identification of high-risk fetuses could lead to better preparation and management of these pregnancies and lead to possible interventions that may alter fetal and birth outcome.

The aim of this study is to investigate the effect of maternal height, weight and lean mass on fetal growth in early, mid and late pregnancy, and to identify when, in pregnancy, any association emerges.

Materials and method

Four hundred twenty-five consecutive women who had their first antenatal clinic visit at the University Hospital of the West Indies, Kingston, Jamaica were informed of the study and agreed to participate. They

lived in the Kingston Metropolitan Area, which is urban. The study was conducted between April 2003 and February 2005. Ninety-seven per cent of the Jamaican population is of West African descent (The Statistical Institute of Jamaica 1996). Written informed consent was obtained from all participants. Sixty-five women (15.3%) were not eligible.

Women who were recruited were less than 15 weeks pregnant, had a singleton pregnancy and did not have any systemic illness such as hypertension, diabetes mellitus or any genetic abnormality, such as sickle cell disease. Once written consent was obtained, a questionnaire was used to record demographics, age, marital status, menstrual history, parity, socio-economic status, medical history and smoking/drinking habits. Socio-economic status was assessed using possessions, amenities, crowding in the home, occupation and educational level of both the women and their partners. A high total score corresponded to high socio-economic status.

At the first antenatal visit, maternal weight was measured to the nearest 0.01 kg using a Tanita digital scale (CMS Weighing Equipment Ltd, London, UK) and height to the nearest 0.1 cm using a stadiometer (CMS Weighing Equipment Ltd). The maternal body mass index was calculated as weight in kilogram divided by height in meter squared (kg m^{-2}). Biceps, triceps, suprailiac and subscapular skinfold thicknesses were measured to the nearest 0.2 mm using a Holtain skinfold caliper (CMS Weighing Equipment Ltd). The technique, sites and marks used to measure the skinfold thickness followed methods described by Harrison (Harrison *et al.* 1988). Each skinfold site was measured three times and the mean was used in the analyses. These measurements were repeated at 15, 25 and 35 weeks gestation.

Subsequent antenatal appointments at 15, 25 and 35 weeks gestation were used to obtain data for early, mid and late pregnancy. At each visit, measurements

Key messages

- There are few studies that have investigated the relationship between maternal size and fetal growth.
- Maternal size has a positive association with fetal growth and birth size.
- There appears to be partitioning of maternal anthropometry affecting different portions of fetal growth.
- Ensuring mothers are well-nourished may help to prevent them from having low-birthweight babies.

of the fetus were made using a curvilinear probe of an ultrasound machine (Voluson 730, Kretztechnik AG, GE Medical Systems, Vienna, Austria); these were biparietal diameter, head circumference, abdominal circumference and femoral length.

Birth measurements were made within 24 h of delivery. Birthweight was measured to the nearest 0.01 kg using a Tanita model 1583 digital baby scale (CMS Weighing Equipment Ltd); crown-heel length was measured to the nearest 0.1 cm using a Harpenden infantometer (CMS Weighing Equipment Ltd). Measurements were made on 10 subjects before the study started to assess the reliability within and between the two trained investigators who performed all subsequent anthropometric measurements. The mean difference between the two measurers was 0.1 mm for biceps skinfold thickness, 0.6 mm for triceps skinfold thickness, 0.2 mm for subscapular skinfold thickness, 0.1 mm for suprailiac skinfold thickness, 0.3 cm for height and 0.01 cm for mid-upper arm circumference. The ratio of between-measurer standard deviation to between-subject standard deviation ranged from 6% for height to 27% for suprailiac. MT performed all the ultrasound measurements.

Body fat and fat-free mass or lean mass were estimated using standard equations (Siri 1961, Durnin & Rahaman 1967). Such methods have been shown to be as accurate as those using more sophisticated techniques such as hydrodensitometry (Presley *et al.* 2000), DEXA Scan and BIA (McCarthy *et al.* 2004). They are convenient, inexpensive, easy and safe. The formula was developed on non-pregnant women as there has been limited research on body composition in pregnancy.

Gestational age was determined from the last menstrual period and confirmed by the ultrasound measurements performed at approximately 15 weeks gestation. If there was a discrepancy of more than 2 weeks, then ultrasound dates were used. The Medical Ethics Committee of the University of the West Indies approved the study.

Statistical methods

Descriptive data were expressed as mean $\pm$ standard deviation. Using the Jamaican fetal growth charts

(Thame *et al.* 2003), we adjusted the observed early, mid and late fetal measurements of head circumference, biparietal diameter, abdominal circumference and femoral length to estimate the values that would have been observed at exactly 15, 25 and 35 weeks of pregnancy. We used multiple linear regression analysis to relate measures of maternal height, weight and lean mass and the adjusted fetal measurements, estimated fetal weight and newborn measurements. We included in the regression analysis as additional predictors maternal age, parity and socio-economic status. We illustrate the results in tables by showing mean values of the fetal and neonatal measure in fourths of the distribution of maternal size. We use the *P*-value for the regression coefficient for maternal size as a continuous measure to convey the strength of linear relationship.

We estimated fetal weight at 15, 25 and 35 weeks of pregnancy using the equation of Shepard (Shepard *et al.* 1982) that is used by the ultrasound machine and based on the measurements of biparietal diameter, head circumference, abdominal circumference and femoral length. The anthropometry at recruitment of women who did not complete the study was compared to women who completed the study using Student's *t*-test. Analyses were performed using SPSS version 19 (IBM, Armonk, NY, USA).

Results

Four hundred twenty-five women who attended The University Hospital agreed to participate in the study and gave informed consent. The analysis was confined to 360 (85%): 43 had early pregnancy losses; 18 defaulted from the study for various reasons (migration, attended other antenatal clinics due to cost); there were two twin pregnancies; two women booked later than 15 weeks as confirmed by an early ultrasound. Only 144 (40%) women were married, none had any significant medical illness, 180 (50%) were primigravidas, 104 (29%) had been pregnant once and 76 (21%) had two or more pregnancies. The women in the study had similar socio-economic scores to each other with a fairly small standard deviation indicating that there was not much diversity (Table 1). Less than

Table 1. Maternal characteristics at the first antenatal visit, ultrasound measurements of intrauterine growth and newborn characteristics

Variables	<i>n</i>	Mean	Standard deviation
Maternal first antenatal visit			
Age (year)	360	23.7	6.5
Weight (kg)	360	65.0	14.0
Height (cm)	360	163.5	5.7
Body mass index (kg m ⁻²)	360	24.3	4.8
Lean mass (kg)	358	45.7	6.6
Gestational age (days)	360	75	17.3
Socio-economic status (score)	360	46.8	4.5
Intrauterine measurements			
15 weeks gestation			
Head circumference (mm)	331	109.6	9.9
Biparietal diameter (mm)	336	30.4	2.6
Abdominal circumference (mm)	337	92.5	9.8
Femoral length (mm)	337	17.5	2.5
Estimated fetal weight (g)	334	129.7	21.1
25 weeks gestation			
Head circumference (mm)	350	227.3	11.1
Biparietal diameter (mm)	349	62.1	3.3
Abdominal circumference (mm)	352	202.5	13.1
Femoral length (mm)	353	45.7	2.5
Estimated fetal weight	346	767.9	121.2
35 weeks gestation			
Head circumference (mm)	332	309.2	11.3
Biparietal diameter (mm)	333	85.6	2.9
Abdominal circumference (mm)	332	307.2	14.5
Femoral length (mm)	329	67.2	2.5
Estimated fetal weight (g)	331	2466.4	295.7
Newborn measurements			
Birthweight (kg)	360	3.02	0.51
Crown-heel length (cm)	356	48.9	2.3
Head circumference (cm)	356	34.2	1.6
Gestational age at birth (days)	360	272	14.3

1% of the women smoked tobacco, drank alcohol or used marijuana.

Table 1 shows descriptive data for the 360 mothers at the first antenatal visit, the intrauterine measurements in early, mid and late pregnancy and the newborn measurements. The 65 women who failed to complete the study were no different from the 360 women in the maternal measurements made at the first antenatal visit ($P > 0.05$ for all comparisons).

Table 2 shows mean fetal measurements at 15, 25 and 35 weeks gestation according to maternal height, weight and lean mass at the first antenatal visit, controlling for maternal age, parity and socio-economic status. The associations between maternal height, weight and lean mass with head circumference and

biparietal diameter became more positive as pregnancy progressed and were statistically significant at 35 weeks gestation. The associations with abdominal circumference were statistically significant at 25 weeks and stronger than at 35 weeks, when it is more difficult to measure. Maternal weight and lean mass were more strongly associated with abdominal circumference than was maternal height. At 35 weeks, height was the maternal variable most strongly associated with femoral length. There were no associations seen between maternal fat mass and fetal or newborn measurements.

Table 3 shows that the associations between maternal height, weight and lean mass, with estimated fetal weight, became more positive as

Table 2. Mean fetal measurements at 15, 25 and 35 weeks gestation according to maternal height, weight and lean mass at the first antenatal visit

Maternal measurement	n	Head circumference (mm)			Biparietal diameter (mm)			Abdominal circumference (mm)			Femoral length (mm)		
		15 weeks	25 weeks	35 weeks	15 weeks	25 weeks	35 weeks	15 weeks	25 weeks	35 weeks	15 weeks	25 weeks	35 weeks
Height (cm)													
<159	81	107.9	225.2	306.5	29.8	61.7	84.4	91.1	199.9	303.5	17.2	45.1	66.6
–163	92	108.9	227.1	307.0	30.2	62.3	85.3	92.0	201.8	307.5	17.3	45.4	67.1
–167	95	111.0	228.9	309.6	31.0	62.3	86.0	93.3	203.9	309.3	17.9	46.0	67.1
>167	92	110.5	227.7	313.1	30.5	62.1	86.4	93.5	204.2	307.6	17.4	46.0	67.6
Change per 5 cm		0.095	0.108	0.208	0.098	0.041	0.206	0.058	0.104	0.063	0.021	0.118	0.125
P for trend		0.071	0.041	0.0001	0.073	0.457	0.0001	0.286	0.058	0.149	0.660	0.016	0.007
Weight (kg)													
<55	90	109.5	226.8	306.5	30.5	62.1	85.3	92.5	199.7	305.1	17.3	45.2	66.9
–62	90	108.4	226.6	307.2	30.1	61.6	85.1	91.5	200.4	304.3	17.1	45.4	67.0
–73	89	110.5	227.1	310.7	30.6	62.2	85.6	93.3	202.5	306.9	17.7	45.6	67.1
>73	91	110.3	228.8	312.0	30.5	62.4	86.4	93.0	207.4	312.2	17.7	46.4	67.9
Change per 5 kg		0.025	0.032	0.079	0.012	0.032	0.059	0.007	0.072	0.055	0.012	0.062	0.046
P for trend		0.273	0.162	0.001	0.610	0.171	0.004	0.778	0.003	0.005	0.579	0.003	0.027
Lean mass (kg)													
<40	62	107.3	226.4	305.9	30.1	61.9	85.1	91.7	198.5	304.5	17.3	44.9	66.8
–45	116	109.8	226.3	307.7	30.4	61.8	85.1	92.4	200.4	304.0	17.4	45.5	67.1
–50	102	110.6	228.4	310.0	30.5	62.2	85.8	93.2	203.9	309.2	17.5	45.8	67.2
>50	78	109.7	227.7	311.9	30.6	62.5	86.3	92.2	206.8	310.2	17.6	46.2	67.7
Change per 5 kg		0.044	0.062	0.153	0.034	0.064	0.124	0.014	0.161	0.096	0.012	0.120	0.065
P for trend		0.338	0.176	0.001	0.476	0.178	0.003	0.774	0.001	0.013	0.786	0.005	0.122

Regression coefficients obtained from a model including maternal age, parity and socio-economic status are expressed as change in fetal measurement per 5 cm (height) or per 5 kg (weight and lean mass). Results represent the predicted mean values from the regression model.

Table 3. Mean estimated fetal weight and newborn measurements according to maternal height, weight and lean mass at first antenatal visit

Maternal measurement	<i>n</i>	Estimated fetal weight (g)			Birthweight (kg)	Crown-heel length (cm)	Head circumference (cm)
		15 weeks	25 weeks	35 weeks			
Height (cm)							
<159	81	125.2	745	2358	2.94	48.5	34.0
–163	92	127.7	765	2456	2.94	48.7	34.1
–167	95	134.3	782	2515	3.10	49.0	34.3
>167	92	130.7	776	2513	3.09	49.2	34.4
Change per 5 cm		1.7	9.3	49.1	0.047	0.293	0.131
<i>P</i> for trend		0.093	0.114	0.001	0.012	0.002	0.04
Weight (kg)							
<55	90	130.2	752	2426	2.88	48.4	33.9
–62	90	126.6	747	2402	3.01	48.8	34.1
–73	89	131.1	770	2462	3.03	49.1	34.3
>73	91	130.9	801	2571	3.16	49.3	34.5
Change per 5 kg		0.2	5.9	20.9	0.037	0.139	0.092
<i>P</i> for trend		0.633	0.019	0.001	0.0001	0.001	0.001
Lean mass (kg)							
<40	62	127.2	744	2403	2.83	48.1	33.9
–45	116	129.2	750	2403	3.00	48.9	34.1
–50	102	130.2	776	2506	3.04	49.0	34.2
>50	78	130.8	798	2534	3.16	49.2	34.5
Change per 5 kg		0.6	13.1	39.8	0.066	0.261	0.184
<i>P</i> for trend		0.504	0.010	0.003	0.0001	0.002	0.001

Regression coefficients obtained from a model including maternal age, parity and socio-economic status are expressed as change in estimated fetal weight and neonatal measurement per 5 cm (height) or per 5 kg (weight and lean mass). Results represent the predicted mean values from the regression model.

pregnancy progressed. All these associations were statistically significant at 35 weeks gestation. The results in Tables 2 and 3 represent the predicted mean values from the regression model. Birthweight, length and head circumference (adjusted for gestational age) were also positively associated with maternal height, weight and lean mass. Fourteen babies (4%) were small for gestational age (birthweight less than the 10th percentile for gestational age) and 43 (12%) were of low birthweight (<2500 g).

Discussion

This study reported the association of maternal size (weight, height and lean body mass) in early pregnancy with fetal size throughout pregnancy and birth size. Maternal measurements made in the first trimester can be used as a proxy of pre-pregnancy size as women do not gain much weight during this period

(Gueri *et al.* 1982), often through vomiting. It is well recognized that maternal weight influences birth size and consequently affects perinatal mortality and morbidity. Few studies have reported the effect of maternal size on fetal growth.

Studies have shown that paternal height influences fetal head circumference and femoral length (Wills *et al.* 2010), while maternal under- or overnutrition, particularly around the peri-implantation period, may impair fetal growth (Wu *et al.* 2004). The consequence of maternal activity is less clear. Fetal growth depends on the woman's fitness and level of exercise (Hatch *et al.* 1993). We had no measures of fitness or exercise level, which may be a limitation. However, maternal nutrition, as measured by weight, height and body composition, is very importantly associated with fetal growth.

Weight has two main components: lean body mass and fat mass. Lean body mass is important for birth size as it is the component of weight that is important

for the laying down of tissue (Thame *et al.* 2007). In this study, lean body mass was also shown to be positively associated with fetal growth.

This study showed an association between maternal size and size at 25 weeks gestation for some fetal measurements. None of the maternal measurements showed an association with fetal size at 15 weeks gestation. The reason for this could be that women do not gain significant weight in the first trimester of pregnancy, that the fetus also grows very slowly at this time and that the signalling of maternal size and fetal growth may not be well developed. However by 25 weeks, these associations begin to emerge, and by 35 weeks, all the fetal measurements were significantly associated with maternal size.

Fetal growth is described by a sigmoid curve. The period of rapid linear growth occurs at approximately 20 weeks gestation and rapid weight gain occurs between 30 and 37 weeks gestation (Lubchenco *et al.* 1963; Hendricks 1964). The emergence of the association of maternal measurements on fetal growth at 25 weeks coincides with this period of rapid growth, suggesting that it is the rapid growth that leads these associations to become clearer. The lighter, shorter women with a lower lean body mass had fetuses with a smaller abdominal circumference and a shorter femoral length. Such women may not be able to sustain adequate growth of the fetus beyond 25 weeks gestation. Hence, the growth rates falter leading to the lighter, shorter fetus. The head size did not show significant faltering in growth until 35 weeks, and it is possible that compensatory mechanisms occurred between the mother and fetus that initially spared fetal head size (Deorari *et al.* 2001; Rosenberg 2008).

Maternal height appeared to have a greater effect on the skeletal growth of the fetus than on the non-skeletal tissue like the abdomen. Taller women had fetuses with longer femoral bones, indicating that maternal skeletal stature influenced fetal skeletal maturation. Similar findings were seen between paternal height, femoral length and head circumference in a study conducted in Pune, India (Wills *et al.* 2010). It is possible that the same factors that influence maternal height may be influencing the fetal skeletal growth, leading to this association. Maternal height was not associated with fetal abdominal circumfer-

ence, unlike maternal weight and lean mass, which had a positive association from as early as 25 weeks gestation. The partitioning of maternal anthropometry affecting different portions of fetal growth may be important, and supports the need for further studies to explore these relationships.

The positive association of maternal size with birth size was confirmed in this study. But this study has also shown that maternal size is associated with fetal weight, femoral length, abdominal circumference and head size, suggesting a continuum and a tracking from *in utero* into post-natal life.

In summary, we have shown an association between maternal measurements in early pregnancy and the size of the fetus at different periods during pregnancy from 25 weeks gestation onwards. Maternal height was most strongly associated with femoral length, while maternal weight and lean mass were most strongly associated with abdominal circumference.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Contributions

All authors have contributed substantially to this manuscript. MT conceived and designed the study, collected the data and together with the other authors prepared the manuscript. CO was the statistician who conducted all the statistical analyses and contributed significantly to writing the manuscript, and HT contributed significantly with the other authors in writing the manuscript.

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