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The effect of maternal and paternal height and weight on antenatal, perinatal and postnatal morphology in sex-stratified analyses

Lise Skåren[1,2] | Braidy Davies[3] | Åshild Bjørnerem[1,4]

[1]Department of Clinical Medicine, UiT The Arctic University of Norway, Tromsø, Norway
[2]Department of Ear, Nose and Throat, Nordland Hospital, Bodø, Norway
[3]Department of Medical Imaging, Mercy Hospital for Women, Heidelberg, Vic., Australia
[4]Department of Obstetrics and Gynecology, University Hospital of North Norway, Tromsø, Norway

Correspondence
Åshild Bjørnerem, Department of Obstetrics and Gynecology, Department of Clinical Medicine, UiT The Arctic University of Norway, N-9037 Tromsø, Norway.
Email: ashild.bjornerem@uit.no

Abstract

Introduction: Low birthweight is associated with diseases later in life. The mechanisms for these associations are not well known. If the hypothesis concerning "maternal constraint" is correct for humans, as shown in animal experiments, we expect the maternal, not paternal, body proportions to influence antenatal growth and those of both parents to influence postnatal growth. We aimed to study the effect of maternal and paternal height and weight on fetal femur length antenatally (gestational weeks 20 and 30) and body length and weight at birth and postnatally (12 and 24 months old) in both sexes.

Material and methods: In this prospective cohort study, 399 healthy pregnant women aged 20-42 years were recruited at The Mercy Hospital for Woman, Melbourne, Australia from 2008 to 2009. Fetal femur length was measured using antenatal ultrasound (gestational weeks 20 and 30). Body length and weight were measured for parents and offspring at birth and postnatally (12 and 24 months).

Results: Each standard deviation (SD) rise in maternal weight (15.5 kg) was associated with 0.24 SD (0.5 mm) and 0.18 SD (0.4 mm) longer femur length in female and male fetuses at week 20 and 0.17 SD (0.5 mm) and 0.38 SD (1.1 mm) longer femur length in female and male fetuses at week 30, respectively. In girls, each SD rise in paternal height (7.2 cm) was associated with 0.29 SD (0.6 cm) longer birth length. In boys, each SD rise in maternal height (6.7 cm) was associated with 0.23 SD (0.5 cm) longer birth length. In both sexes, parental height and weight were associated with offspring length and weight at 12 and 24 months (SD ranging from 0.20 to 0.38, length from 0.7 to 1.5 cm and weight from 0.3 to 0.6 kg). The multivariable linear regression analyses were adjusted for parental age, height and weight, maternal smoking, alcohol intake, parity, and ethnicity, all $P < 0.05$.

Conclusions: Maternal, not paternal, body proportions determined fetal growth in both sexes. Paternal height predicted birth length in girls. In contrast, maternal height predicted birth length in boys. Both parents predicted postnatal body proportions at 12 and 24 months in both sexes.

Abbreviations: AC, abdominal circumference; BMI, body mass index; EFW, estimated fetal weight; FL, femur length; HC, head circumference; IGF, insulin-like growth factor.

KEYWORDS
birth length, birthweight, fetal femur length, infant length and weight, maternal height and weight, paternal height and weight

1 | INTRODUCTION

Poor fetal growth with subsequent low birthweight is reported to be associated with an increased risk for diseases later in life, including cardiovascular disease, diabetes mellitus, reduced bone mass and hip fractures.[1,2] The variation in fetal dimensions has a large genetic component, although environmental factors also contribute to this variation.[3] The mechanisms for these associations are not well known, but increasing the understanding of the determinants for the patterns of intrauterine growth and development may contribute to the optimization of health in adulthood.

Maternal constraint of fetal growth is considered to be the major non-genetic factor determining the size of the fetus at term, especially in young mothers, small mothers, nullipara mothers and mothers with multiple pregnancies.[4-7] Reference is made to "processes by which maternal and uteroplacental factors act to limit the growth of the fetus, presumably by limiting nutrient availability and/or the metabolic-hormonal drive to grow",[5] to enhance the mother's ability to deliver her offspring successfully and ensure her own survival.[6] Both genetic and epigenetic maternal factors expressed in the placenta may contribute to limiting fetal growth.[5] This may have long-term consequences because increasing evidence suggests that poor fetal growth resulting from maternal constraint may lead to increased risk of chronic diseases in adulthood.[1,2]

There is no doubt that maternal body proportions influence fetal growth. The paternal role is less clear, as there is little data on how the paternal body proportions influence fetal growth.[8] The paternal body proportions are associated with the offspring's birthweight.[9-11] Although maternal weight had a greater impact on birthweight than paternal weight, this finding suggested that paternal genetic factors still influence birthweight independently of maternal factors.[10] Others have reported that paternal height had an effect on the offspring's birthweight, whereas the paternal body mass index (BMI) did not.[12] They demonstrated maternal constraint by showing that the father's height had a small effect on birthweight if the mother was short.[12] Maternal and paternal height and weight contribute similarly to postnatal weight gain.[10]

The aims of this study were to determine the effect of maternal and paternal height and weight on fetal femur length (FL) in the antenatal period (gestational weeks 20 and 30) and the body length and weight at birth and in the postnatal period (12 and 24 months old) in girls and boys. We investigated a cohort from the general population in Australia with mainly Caucasian participants. We hypothesized that (1) fetal FL and neonatal length and weight are more strongly associated with maternal body proportions than paternal body proportions in both sexes due to maternal constraint and that (2) postnatal length and weight are associated similarly with maternal and paternal height and weight in both sexes after release from maternal constraint.

Key message

Maternal, not paternal, body proportions influenced fetal growth in both sexes. Paternal height determined birth length in girls, but maternal height determined birth length in boys. Both parents influenced the postnatal infant body proportions at 24 months in both sexes.

2 | MATERIAL AND METHODS

2.1 | Design and population

In this prospective cohort study, 399 healthy pregnant women aged 20-42 years with a single normal fetus were recruited at their 20-week gestation routine ultrasound scan at The Mercy Hospital for Women in Melbourne, Australia between July 2008 and June 2009.[8] Among these women, 43 were lost to follow up, 356 were willing to have an additional ultrasound at gestational week 30, and 370 women and 345 of their partners had their height and weight measured. For the sex-stratified analysis, among those who had the sex disclosed after birth, we included 336 (172 female and 164 male) fetuses with their FLs measured at gestational week 20 and 328 (166 female and 162 male) fetuses with their FLs measured at gestational week 30. After birth, 282 term newborns (138 girls and 144 boys), 165 infants (82 girls and 83 boys) at 12 months, and 201 infants (101 girls and 100 boys) at 24 months were willing to participate in a follow-up for height and weight measurements.

2.2 | Variables

Gestation was determined based on the last menstrual period unless the gestational age based on the first ultrasound measurement (crown-rump length before gestational week 14 or biparietal diameter, abdominal circumference [AC] and FL at gestational weeks 12-20) differed by >7 days; in such cases, gestational age was based on the ultrasound assessments. Fetal growth was monitored using 2-dimensional ultrasound assessments of head circumference (HC), AC, FL and estimated fetal weight (EFW) on 2 occasions: at gestational weeks 20 (range 17-23) and 30 (range 27-34). HC, AC and FL are the routine measurements to assess gestational age and growth with high reproducibility. The measurements were obtained by 2 experienced ultrasonographers using a Philips IU22, GE Voluson

HDI-5000 or a GE Voluson HDI-3000 ultrasound machine. We excluded fetuses who had major malformations detected by ultrasound scan and newborns who were delivered preterm before gestational week 37. A questionnaire about maternal lifestyle, such as current smoking and alcohol use, parity, and country of birth, to classify the mothers' ethnicity, was distributed. Of the 370 women who completed the questionnaires, 279 (75.4%) women reported that they were Caucasians, while 24.6% were of different multiethnic origins, mainly from Asian countries.

Following birth (1-7 days of age) and at 12 and 24 months of age, crown-heel length and weight were measured by 2 trained researchers. Crown-heel length was measured to the nearest 0.1 cm using a length board (Ellard Instrumentation Ltd, Seattle, WA, USA), and weight was measured on regularly calibrated scales. Parental height was measured to the nearest 0.1 cm using a Holtain stadiometer fixed on the wall, and weight was measured to the nearest 0.1 kg using an electronic scale while wearing light clothing without shoes at gestational week 30.

2.3 | Statistical analyses

All variables were checked for normality by visual inspection of the histograms. Royston models were fitted to the fetal and infant growth measurements to create z-scores for the size measurements during growth.[13] Linear regression models were used to explore the relation between parental height and weight (exposures) with offspring antenatal HC, AC, FL and EFW and postnatal length and weight *z*-scores (outcomes) in the sex-stratified analysis. Standardized regression coefficients were used to facilitate the comparison of the strength of the associations between the exposures and outcomes per standard deviation (SD) unit. The univariate models included the maternal and paternal heights and weights alone. In multivariable models, parental height and weight, maternal age, smoking (no vs yes), alcohol intake during gestation (no vs yes), primipara (no vs yes), Caucasian ethnicity (no vs yes) and paternal age were considered as covariates. The P-value for entering covariates was $P < 0.25$ and that for deleting covariates was $P > 0.10$. The $P < 0.05$ was considered significant in the final model.[14] SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA) was used for data analyses.

2.4 | Ethical approval

All participants gave written informed consent. Mercy Health & Aged Care Human Research Ethics Committee approved the study (Project number R08/14).

3 | RESULTS

The characteristics of the participants are shown in Table 1. The mean ± SD maternal height and weight were 164.3 ± 6.7 cm and 76.9 ± 15.5 kg, and the paternal height and weight were 177.7 ± 7.2 cm and 86.9 ± 14.1 kg, respectively. The male fetuses had larger HC and AC than the females at gestational week 20 and larger HC at gestational week 30. FL and EFW did not differ between female and male fetuses at gestational weeks 20 and 30. The boys were 0.8, 2.1 and 1.8 cm longer than the girls at birth and 12 and 24 months after birth and 0.11, 0.86 and 0.93 kg heavier than girls at birth and 12 and 24 months after birth, respectively.

In both sexes, maternal, not paternal, body proportions were associated with fetal FL (Table 2). Each SD rise in maternal weight was associated with a 0.24 SD (0.5 mm) and 0.17 SD (0.5 mm) longer FL at gestational weeks 20 and 30 in female fetuses, respectively, and a 0.18 SD (0.4 mm) and 0.38 SD (1.1 mm) longer FL at gestational weeks 20 and 30 in male fetuses, respectively. Maternal height was associated with larger HC at gestational week 20 in male fetuses and larger HC and EFW at gestational week 30 in both sexes. Maternal weight was associated with larger AC at gestational week 30 in both sexes and larger EFW at gestational week 30 in male fetuses. Paternal height was associated with larger AC and EFW at gestational week 30 in female fetuses.

In girls, only paternal height was associated with birth length and with weight and length at 12 months (Table 3). Each SD rise in paternal height increased the birth length by 0.29 SD (0.6 cm) and weight and length at 12 months by 0.28 SD (0.34 kg) and 0.36 SD (1.1 cm), respectively. Each SD rise in maternal height and paternal height increased the birthweight by 0.23 SD (0.09 kg) and 0.21 SD (0.08 kg), respectively. Each SD rise in maternal weight and paternal height increased the weight at 24 months by 0.21 SD (0.32 kg) and 0.20 SD (0.30 kg), respectively. Each SD rise in maternal and paternal height increased the length at 24 months by 0.21 SD (0.8 cm) and 0.33 SD (1.3 cm), respectively.

In boys, only maternal height was associated with birth length and weight at 12 months. Each SD rise in maternal height increased the birth length by 0.23 SD (0.5 cm) and weight at 12 months by 0.24 SD (0.29 kg). Each SD rise in maternal height and weight increased the birthweight by 0.22 SD (0.11 kg) and 0.23 SD (0.12 kg), respectively. Each SD rise in maternal height, maternal weight and paternal weight increased the length at 12 months by 0.23 SD (0.7 cm), 0.22 SD (0.7 cm) and 0.32 SD (1.0 cm), respectively. Each SD rise in maternal weight and paternal weight increased the weight at 24 months by 0.34 SD (0.58 kg) and 0.27 SD (0.46 kg), respectively. Each SD rise in maternal weight and paternal height increased the length at 24 months by 0.33 SD (1.3 cm) and 0.38 SD (1.5 cm), respectively.

All results from the above-mentioned multivariable linear regression analysis were mutually adjusted for parental height and weight and adjusted for maternal age, smoking, alcohol intake during gestation, parity, ethnicity and paternal age, and all P values were < 0.05.

4 | DISCUSSION

We reported that maternal, not paternal, body proportions predicted antenatal growth of FL. Only paternal height predicted the

TABLE 1 Characteristics of mothers, fathers and offspring during gestation and after birth

	n	Mothers	n	Fathers	*P* value
Age (y)	370	31.3 ± 4.5	318	33.8 ± 5.7	
Height (cm)	370	164.3 ± 6.7	345	177.7 ± 7.2	
Weight (kg)	370	76.9 ± 15.5	345	86.9 ± 14.1	
Caucasian ethnicity, n (%)	370	279 (75.4)			
Primipara, n (%)	355	166 (46.8)			
Smoking, n (%)	356	30 (8.4)			
Alcohol, n (%)	354	74 (20.9)			
		Girls		**Boys**	
Fetuses					
Gestational age at 20 weeks (wk)	171	19.8 ± 0.7	163	19.9 ± 0.8	0.077
Head circumference (cm)	172	16.9 ± 1.0	164	17.4 ± 1.1	<0.001
Abdominal circumference (cm)	169	14.9 ± 1.1	162	15.4 ± 1.1	<0.001
Femur length (cm)	171	3.1 ± 0.2	164	3.2 ± 0.2	0.145
Estimated fetal weight (kg)	94	0.32 ± 0.50	90	0.34 ± 0.54	0.065
Gestational age at 30 weeks (wk)	166	30.4 ± 1.1	162	30.4 ± 1.1	0.986
Head circumference (cm)	167	28.0 ± 1.3	162	28.4 ± 1.2	0.002
Abdominal circumference (cm)	167	27.3 ± 1.8	162	27.3 ± 1.6	0.834
Femur length (cm)	166	5.8 ± 0.3	162	5.8 ± 0.3	0.162
Estimated fetal weight (kg)	156	1.70 ± 0.27	155	1.70 ± 0.26	0.897
Term neonates					
Gestational age (wk)	138	39.6 ± 1.1	144	39.7 ± 1.2	0.763
Birth length (cm)	138	50.7 ± 2.1	144	51.5 ± 2.0	0.001
Birthweight (kg)	138	3.5 ± 0.4	144	3.6 ± 0.5	0.049
Infants					
Age at 12 months (mo)	82	14.3 ± 1.9	83	14.4 ± 1.8	0.680
Body length (cm)	82	77.4 ± 3.1	83	79.5 ± 3.1	<0.001
Body weight (kg)	82	10.2 ± 1.1	83	11.0 ± 1.2	<0.001
Age at 24 months (mo)	101	27.9 ± 2.9	100	28.1 ± 2.7	0.616
Body length (cm)	101	90.5 ± 4.0	100	92.2 ± 4.0	0.002
Body weight (kg)	100	13.3 ± 1.5	100	14.2 ± 1.7	<0.001

Note: Values are mean ± SD for continuous variables and number (%) for categorical variables.
Variation in numbers within groups were due to missings and *P* values were calculated using *t* tests.

birth length in girls, and only maternal height predicted the birth length in boys, both of which were independent of the other parental body proportions and potential confounders. The same pattern was found for body weight and length in girls at 12 months and body weight in boys at 12 months after birth. The body proportions of both parents influenced the body weight and length of the offspring at 24 months after birth in both sexes.

First, we confirmed that paternal height and weight were not associated with the antenatal growth measurement of fetal FL. This is in agreement with our previous report that paternal FL and knee-heel length were not associated with the corresponding fetal traits.[8] We found that maternal weight was the main independent predictor of fetal FL in both female and male fetuses, which is in agreement with the previous finding that the maternal FL and knee-heel length are associated with the corresponding fetal traits.[8] The reasons for the clear association between maternal traits and antenatal growth are probably a combination of genetic, epigenetic and environmental factors.[5]

TABLE 2 The effect of parental height and weight on fetal head circumference (HC), abdominal circumference (AC), femur length (FL) and estimated fetal weight (EFW) z-scores in girls and boys at gestational weeks 20 and 30

	Girls				Boys			
	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value
Fetal HC weeks 20								
Maternal height	0.09 (−0.05 to 0.23)	0.225			0.19 (0.14 to 0.33)	0.019	0.20 (0.06 to 0.34)	0.012
Maternal weight	0.12 (−0.02 to 0.26)	0.129			0.09 (−0.07 to 0.25)	0.238		
Paternal height	0.02 (−0.12 to 0.16)	0.754			−0.03 (−0.21 to 0.15)	0.763		
Paternal weight	−0.04 (−0.18 to 0.10)	0.623			−0.10 (−0.26 to 0.06)	0.250		
Fetal AC weeks 20								
Maternal height	0.13 (−0.03 to 0.29)	0.106			0.24 (0.10 to 0.38)	0.002		
Maternal weight	0.14 (0.00 to 0.28)	0.075			0.14 (−0.02 to 0.30)	0.070		
Paternal height	0.09 (−0.05 to 0.33)	0.275			−0.03 (−0.21 to 0.15)	0.764		
Paternal weight	−0.00 (−0.16 to 0.16)	0.962			0.02 (−0.14 to 0.18)	0.767		
Fetal FL weeks 20								
Maternal height	0.12 (−0.04 to 0.28)	0.134			0.11 (−0.03 to 0.25)	0.170		
Maternal weight	0.22 (0.06 to 0.38)	0.004	0.24 (0.08 to 0.40)	0.002	0.21 (0.07 to 0.35)	0.009	0.18 (0.02 to 0.34)	0.029
Paternal height	0.04 (−0.10 to 0.18)	0.573			0.00 (−0.18 to 0.18)	0.983		
Paternal weight	0.11 (−0.05 to 0.37)	0.180			0.00 (−0.16 to 0.16)	0.958		
Fetal EFW weeks 20								
Maternal height	0.11 (−0.11 to 0.33)	0.282			0.18 (−0.02 to 0.38)	0.089	0.18 (−0.02 to 0.38)	0.089
Maternal weight	0.18 (−0.02 to 0.38)	0.087			0.09 (−0.13 to 0.31)	0.406		
Paternal height	0.01 (−0.19 to 0.21)	0.961			−0.02 (−0.28 to 0.24)	0.860		
Paternal weight	0.09 (−0.15 to 0.33)	0.374			−0.03 (−0.15 to 0.21)	0.769		
Fetal HC weeks 30								
Maternal height	0.26 (0.10 to 0.42)	<0.001	0.26 (0.10 to 0.42)	<0.001	0.41 (0.14 to 0.55)	<0.001	0.42 (0.28 to 0.56)	<0.001
Maternal weight	0.04 (−0.12 to 0.20)	0.628			0.20 (0.04 to; 0.36)	0.012		
Paternal height	0.12 (−0.02 to 0.26)	0.125			0.12 (−0.06 to 0.30)	0.146		

(Continues)

TABLE 2 (Continued)

	Girls				Boys			
	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value
Paternal weight	0.05 (−0.11 to 0.21)	0.559			0.07 (−0.09 to 0.23)	0.420		
Fetal AC weeks 30								
Maternal height	0.16 (0.00 to 0.32)	0.042			0.17 (0.01 to 0.33)	0.029		
Maternal weight	0.18 (0.04 to 0.32)	0.019	0.17 (0.01 to 0.33)	0.032	0.28 (0.12 to 0.44)	<0.001	0.18 (0.02 to 0.34)	0.019
Paternal height	0.22 (0.08 to 0.36)	0.006	0.19 (0.05 to 0.33)	0.015	−0.02 (−0.20 to 0.20)	0.845		
Paternal weight	0.09 (−0.07 to 0.25)	0.249			0.06 (−0.12 to 0.24)	0.483		
Fetal FL weeks 30								
Maternal height	0.20 (0.04 to 0.36)	0.011	0.16 (−0.02 to 0.34)	0.048	0.15 (−0.01 to 0.31)	0.052		
Maternal weight	0.21 (0.05 to 0.37)	0.008	0.17 (0.01 to 0.33)	0.040	0.29 (0.13 to 0.45)	<0.001	0.38 (0.20 to 0.56)	<0.001
Paternal height	0.15 (0.01 to 0.29)	0.069			0.13 (−0.05 to 0.31)	0.129	0.15 (−0.05 to 0.35)	0.062
Paternal weight	0.09 (−0.07 to 0.25)	0.272			0.08 (−0.08 to 0.24)	0.321		
Fetal EFW weeks 30								
Maternal height	0.27 (0.11 to 0.43)	<0.001	0.18 (0.02 to 0.34)	0.035	0.27 (0.11 to 0.43)	0.001	0.17 (−0.01 to 0.35)	0.041
Maternal weight	0.18 (0.02 to 0.34)	0.029			0.34 (0.18 to 0.50)	<0.001	0.25 (0.07 to 0.43)	0.003
Paternal height	0.30 (0.16 to 0.44)	<0.001	0.22 (0.06 to 0.38)	0.009	0.04 (−0.18 to 0.26)	0.613		
Paternal weight	0.15 (−0.01 to 0.31)	0.076			0.08 (−0.10 to 0.26)	0.339		

Note: Numbers are standardized beta coefficients (β) with 95% CI in [a]unadjusted and [b]multivariable linear regression models including maternal and paternal heights and weights, maternal age, primipara (no vs yes), Caucasian ethnicity (no vs yes), smoking (no vs yes) alcohol intake (no vs yes) and paternal age. We used *P* value < 0.25 for entering variables and *P* value > 0.10 for deleting variables. *P* < 0.05 was considered significant.

Second, in this current study, maternal traits had the most important effect on birthweight in both sexes, which fits with the theories of maternal constraint[5] and the results of a previous report.[9] However, we did not expect to discover that paternal height predicted birth length in girls independently of maternal height, and there was no independent effect of maternal height itself on the birth length of girls. In contrast, maternal height predicted birth length in boys independently of paternal height, and there was no independent effect of paternal height itself on the birth length of boys. We do not know the reasons for these findings. We speculate that as boys have a tendency to grow faster and become larger than girls, they may need to be more "constrained" by the mother for her own survival.[15-17] Paternal height has been reported to be more strongly associated with bone mineral density in newborn girls than in boys, and this effect was also independent of maternal influence.[18] Male mice were reported to be more adversely affected than female mice after experiencing fetal growth restrictions by bilateral uterine vessel ligation.[19] The growth-restricted fetuses had a low birthweight for gestational age, a low cortical bone mass during early postnatal life, and low bone bending strength that remained low at 6 months of age, which may lead to a predisposition for fractures later in life.[19] The mouse model findings suggest a sex-specific programming of the outcomes, as the deficits were corrected by postnatal nutrition for females born small, but not for males.[19]

Results from other studies differ from our findings.[20-25] In a retrospective multicenter study, paternal and maternal height and maternal weight were associated with fetal HC, AC and FL.[20,21] In the Intergrowth-21st study, fathers of infants born large-for-gestational-age were taller and heavier but they had similar BMI.[22] Paternal height predicted large-for-gestational-age in boys and girls, but paternal BMI was not associated with greater odds ratio

TABLE 3 The effect of parental height and weight on neonatal birth length, and the birthweight z-scores and body length and weight z-scores of the infants at 12 and 24 months of age

	Girls				Boys			
	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value
Birthweight								
Maternal height	0.32 (0.16 to 0.48)	<0.001	0.23 (0.07 to 0.39)	<0.001	0.38 (0.24 to 0.52)	<0.001	0.22 (0.06 to 0.38)	0.013
Maternal weight	0.22 (0.06 to 0.38)	0.010			0.36 (0.20 to 0.52)	<0.001	0.23 (0.07 to 0.39)	0.007
Paternal height	0.31 (0.15 to to 0.47)	<0.001	0.21 (0.05 to 0.37)	0.015	0.15 (−0.05 to 0.35)	0.093		
Paternal weight	0.15 (−0.03 to 0.33)	0.081			0.10 (0.08 to 0.28)	0.373		
Birth length								
Maternal height	0.22 (0.04 to 0.40)	0.009			0.33 (0.19 to 0.47)	<0.001	0.23 (0.07 to 0.39)	0.011
Maternal weight	0.13 (−0.05 to 0.41)	0.135			0.21 (0.05 to 0.37)	0.013		
Paternal height	0.29 (0.13 to 0.45)	<0.001	0.29 (0.13 to 0.45)	<0.001	0.22 (0.04 to 0.40)	0.009	0.16 (−0.02 to 0.34)	0.054
Paternal weight	0.09 (−0.09 to 0.27)	0.291			0.16 (0.00 to 0.32)	0.072		
Weight 12 months								
Maternal height	0.07 (−0.13 to 0.27)	0.515			0.35 (0.17 to 0.53)	0.001	0.24 (0.04 to 0.44)	0.036
Maternal weight	0.14 (−0.04 to 0.32)	0.213			0.29 (0.09 to 0.49)	0.008		
Paternal height	0.28 (0.12 to 0.44)	0.013	0.28 (0.12 to 0.44)	0.010	0.18 (−0.06 to 0.42)	0.123		
Paternal weight	0.07 (−0.11 to 0.25)	0.547			0.15 (0.05 to 0.35)	0.195		
Length 12 months								
Maternal height	0.28 (0.06 to 0.50)	0.010	0.20 (−0.04 to 0.44)	0.095	0.34 (0.16 to 0.52)	0.002	0.23 (0.05 to 0.41)	0.045
Maternal weight	0.09 (−0.11 to 0.29)	0.419			0.31 (0.11 to 0.51)	0.005	0.22 (0.02 to 0.42)	0.053
Paternal height	0.38 (0.10 to 0.66)	<0.001	0.36 (0.16 to 0.56)	0.003	0.35 (0.13 to 0.57)	0.002		
Paternal weight	0.03 (−0.19 to 0.25)	0.775			0.36 (0.18 to 0.54)	0.001	0.32 (0.16 to 0.48)	0.002
Weight 24 months								
Maternal height	0.23 (0.07 to 0.41)	0.019			0.22 (0.04 to 0.40)	0.025		
Maternal weight	0.29 (0.11 to 0.47)	0.003	0.21 (0.03 to 0.39)	0.031	0.39 (0.21 to 0.57)	<0.001	0.34 (0.16 to 0.52)	<0.001
Paternal height	0.23 (0.07 to 0.39)	0.023	0.20 (−0.04 to 0.36)	0.042	0.28 (0.06 to 0.50)	0.008		
Paternal weight	0.24 (0.04 to 0.44)	0.016			0.33 (0.15 to 0.51)	0.001	0.27 (0.09 to 0.55)	0.005
Length 24 months								
Maternal height	0.36 (0.18 to 0.54)	<0.001	0.21 (0.03 to 0.39)	0.032	0.35 (0.17 to 0.53)	<0.001		

(Continues)

TABLE 3 (Continued)

	Girls				Boys			
	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value	β (95% CI)[a]	*P* value	β (95% CI)[b]	*P* value
Maternal weight	0.22 (0.04 to 0.40)	0.028			0.3 (0.2 to 0.5)	<0.001	0.33 (0.15 to 0.51)	<0.001
Paternal height	0.40 (0.24 to 0.56)	<0.001	0.33 (0.17 to 0.49)	0.001	0.3 (0.1 to 0.6)	0.001	0.38 (0.16 to 0.60)	<0.001
Paternal weight	0.17 (−0.03 to 0.37)	0.096			0.3 (0.1 to 0.5)	<0.001		

Numbers are standardized beta coefficients (β) with 95% CI in [a]unadjusted and [b]multivariable linear regression models including maternal and paternal heights and weights, maternal age, primipara (no vs yes), Caucasian ethnicity (no vs yes), smoking (no vs yes), alcohol intake (no vs yes) and paternal age. We used *P* value < 0.25 for entering variables and *P*-value > 0.10 for deleting variables. The *P* value < 0.05 were considered significant.

for having large-for-gestational-age boy or girl after adjustment for maternal BMI.[22] Others reported maternal and paternal height and maternal BMI, not paternal BMI, associated with birthweight.[23] Maternal-child BMI association has been reported to be stronger than paternal-child BMI at birth, 1 year and 7 years in both girls and boys.[24] Similar associations between maternal-child BMI and paternal-child BMI at 3 years have been reported;[25] and as others,[26] they questioned the contribution by the intrauterine environment and suggested that prevention of childhood adiposity will benefit more from postnatal than prenatal intervention.[25] The role of ethnicity is not clear, as a small effect on fetal biometry is reported in some studies,[20,21] the large Intergrowth-21st study found no effect of ethnicity after adjustment for socioeconomic confounders,[27] which supports the Barker hypothesis.[1,2]

There is some disagreement about the mechanism behind maternal constraint and possible explanations that have been suggested are: (1) maternal regulation of fetal nutrition, (2) maternal hormone regulation, or (3) cytoplasmic inheritance.[28] The theory concerning cytoplasmic inheritance suggests that the ovum contains growth-regulating substances that will reflect the size of the mother and determine the fetal size at birth.[28] In a study of the role of environmental vs genetic factors in the determination of birthweight following ovum donation, birthweight correlated with recipient traits and not donor traits.[4] Therefore, cytoplasmic inheritance alone cannot explain maternal constraint. If cytoplasmic inheritance was the only factor, then the donor traits, not recipient's traits, should have been reflected in the offspring.

An alternative explanation for maternal constraint involves imprinted genes and the parent-offspring conflict theory.[15] In studies with mice, several imprinted genes were reported to play an important role in the regulation of fetal growth, and the paternally expressed genes enhanced fetal growth, while the maternally expressed genes suppressed fetal growth.[15] This is linked to the insulin and insulin-like growth factor (IGF) system. IGF-2 is expressed by a paternal gene that enhances fetal growth, whereas the maternally expressed IGF2-receptor is a suppressor of fetal growth.[15] This gives rise to the parent-offspring conflict theory, in which the mother downregulates fetal growth to avoid difficulties during parturition and wishes to reserve resources for future offspring. On the other hand, the father extracts more resources to maximize fetal growth. Several studies have shown that a large proportion of the imprinted genes that influence fetal growth work in such an antagonistic manner.[29] The evidence is based on the following 6 points for mammalian genomic imprinting: (1) pronuclear transplantation-type experiments in mice, (2) phenotypes of triploids in humans, (3) expression of certain types of chromosomal disomy in mice and humans, (4) phenotypic expression of chromosomal deficiencies in mice and humans, (5) expression of transgene genetic material in transgenic mice; and (6) expression of specific genes in mice and humans.[16]

Third, our findings that both maternal and paternal body proportions predicted the weight and length at 24 months after birth in both sexes are in agreement with a previous report that found a similar contribution of both parents on offspring weight gain after birth.[9,25]

The strength of this study is the relatively large sample size and the standardized research setting for obtaining the measurements of both the parents and offspring rather than using self-reported measurements of height and weight. However, the study has some limitations. The best way to assess age in the antenatal period, based on the first day of the last menstrual period, is prone to errors because the interval from menstruation to fertilization varies from 8 to 20 days.[30] The measurement errors may dilute the true associations and lead to an underestimation of the associations, and the results must therefore be interpreted with caution. The lack of information on nutrition and food intake, which may influence postnatal growth, is another limitation. Nutrition is generally good within Australia but there are individual variations in food consumption that are not covered by this study that may affect fetal and newborn growth.

5 | CONCLUSION

The maternal, not paternal, body proportions determined growth of fetal FL. In the sex-stratified analyses, paternal, not maternal, height determined birth length in girls, and maternal, not paternal, height determined birth length in boys. These findings of sex-based differences, in which maternal height predicts birth length in boys, and paternal height predicts birth length in girls, need to be confirmed and further explored in other studies. We confirmed that the body proportions of both parents influenced postnatal growth. Growth is multifactorial and we have explored some factors contributing to growth. It will be of clinical interest to clarify the role of the intrauterine environment to better understand the many factors contributing to growth abnormality. Further investigation of prenatal growth and postnatal growth and how growth in these periods may prevent adult diseases is needed.

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CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

ORCID

Lise Skåren https://orcid.org/0000-0002-3927-1225

Braidy Davies https://orcid.org/0000-0001-7269-8143

Åshild Bjørnerem https://orcid.org/0000-0002-3123-2950

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