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MATERNAL HEIGHT AND PRE-PREGNANCY WEIGHT STATUS ARE ASSOCIATED WITH FETAL GROWTH PATTERNS AND NEWBORN SIZE

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Summary. The impact of maternal height, pre-pregnancy weight status and gestational weight gain on fetal growth patterns and newborn size was analysed using a dataset of 4261 singleton term births taking place at the Viennese Danube Hospital between 2005 and 2013. Fetal growth patterns were reconstructed from three ultrasound examinations carried out at the 11th/12th, 20th/21th and 32th/33th weeks of gestation. Crown–rump length, biparietal diameter, fronto-occipital diameter, head circumference, abdominal transverse diameter, abdominal anterior–posterior diameter, abdominal circumference and femur length were determined. Birth weight, birth length and head circumference were measured immediately after birth. The vast majority of newborns were of normal weight, i.e. between 2500 and 4000 g. Maternal height showed a just-significant but weak positive association ($r = 0.03$: $p = 0.039$) with crown–rump length at the first trimester and with the majority of fetal parameters at the second trimester ($r > 0.06$; $p < 0.001$) and third trimester ($r > 0.09$; $p < 0.001$). Pre-pregnancy weight status was significantly positively associated with nearly all fetal dimensions at the third trimester ($r > 0.08$; $p < 0.001$). Maternal height ($r > 0.17$; $p < 0.001$) and pre-pregnancy weight status ($r > 0.13$; $p < 0.001$), but also gestational weight gain ($r > 0.13$; $p < 0.001$), were significantly positively associated with newborn size. Some of these associations were quite weak and the statistical significance was mainly due to the large sample size. The association patterns between maternal height and pre-pregnancy weight status with fetal growth patterns ($p < 0.001$), as well as newborn size ($p < 0.001$), were independent of maternal age, nicotine consumption and fetal sex. In general, taller and heavier women gave birth to larger infants. This association between maternal size and fetal growth patterns was detectable from the first trimester onwards.

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Introduction

Newborn size – commonly determined by measuring weight, length and head circumference immediately after birth – is an important indicator of infant survival and also morbidity during childhood and adult life (Barker, 1998; Gluckman *et al.*, 2008; Chandler-Laney *et al.*, 2013). Furthermore, especially high birth weight is associated with obstetrical problems such as an increased risk of artificial induction of labour, prolonged birth, birth asphyxia and increased rates of Caesarian section (Mocanu *et al.*, 2000). Newborn size, however, is the result of fetal growth patterns. Therefore the identification of factors influencing fetal growth and consequently newborn size are of special interest to gynaecologists, perinatologists and public health researchers (Thame *et al.*, 2004).

It is well known that fetal growth is influenced by genetic and several environmental factors (Lunde *et al.*, 2007). In particular, maternal height, pre-pregnancy weight status and pregnancy weight gain have been identified as major determinants of fetal growth patterns and consequently newborn size (Kirchengast & Hartmann, 1998; Kirchengast *et al.*, 1998; Pickett *et al.*, 2000; Brown *et al.*, 2002; Clausen *et al.*, 2005; Thame *et al.*, 2004; Cedergren, 2006; Johansson *et al.*, 2007; Kabali & Werler, 2007; Crane *et al.*, 2009; Dietz *et al.*, 2009; Choi *et al.*, 2011; Han *et al.*, 2011; Mitra *et al.*, 2012; Hanieh *et al.*, 2014). Only a few studies have documented an impact of paternal height and weight status on intrauterine growth patterns (Wilcox *et al.*, 1995; Klebanoff *et al.*, 1998; Wills *et al*., 2010, Albouy-Llaty *et al.*, 2011). Maternal and paternal height reflect above all the genetic potential for growth (Wills *et al.*, 2010). Maternal height, however, also reflects the early environmental conditions of the mother (Wills *et al*., 2010). In contrast, maternal pre-pregnancy weight status and pregnancy weight gain are major indicators of the actual environmental conditions.

Several studies have shown an association between maternal height, maternal pre-pregnancy weight and pregnancy weight gain with newborn size (Kirchengast & Hartmann, 1998, 2003). It is well established that newborn size is positively correlated with maternal pre-pregnancy weight status as well as pregnancy weight gain (Takimoto *et al.*, 2006; Kalanda, 2007; Catalano *et al.*, 2014). Newborn size, however, is the result of intrauterine growth patterns. Consequently, an association between maternal somatic factors and fetal growth patterns can be assumed. Fetal growth patterns are mostly estimated by ultrasound scans. The parameters most frequently measured *in utero* are crown–rump length, femur length, biparietal diameter, head circumference, transverse abdominal diameter and abdominal circumference (Harada *et al.*, 1992; Davis *et al.*, 1993; Marsal *et al.*, 1996; Lee *et al.* 2009; Albouy-Llaty *et al.*, 2011).

Unfortunately only very few studies have focused on the associations between maternal factors and intrauterine growth patterns estimated by prenatal ultrasound measurements (Schwärzler *et al.*, 2004; Thame *et al.*, 2004; Drooger *et al.*, 2005; Ay *et al.*, 2009; Sarris *et al.*, 2010; Lampl *et al.*, 2010; Wills *et al.*, 2010; Albouy-Llaty *et al.*, 2011). The impact of maternal height and weight on fetal growth has predominantly been analysed in multiparous (Goldenberg *et al.*, 1993) and high-risk women (de Joung *et al.*, 1998; Hinkle *et al.*, 2015). In general it could be shown that maternal characteristics are associated with fetal size in the second and third trimester (Leung *et al.*, 2008; Salpou *et al.*, 2008). No significant correlation between maternal weight status and crown–rump length could be proved for the first trimester (Sarris *et al.*, 2010).

The aims of the present study were, first, to analyse the association patterns between maternal height and pre-pregnancy weight status with fetal growth parameters during the first, second and third trimesters of pregnancy. In a second step the association patterns between maternal height, pre-pregnancy weight status and gestational weight gain with newborn size were tested.

Methods

Data set

This retrospective study was based on a data set of 4261 singleton births taking place at the Danube Hospital (SMZ Ost) in Vienna, Austria, between 2005 and 2013. Although over this period 17,430 births were recorded at the hospital, only for 7590 births had all three prenatal ultrasound examinations been performed. Furthermore, the following strict inclusion criteria were defined for inclusion in the study, reducing the sample to 4261: all recommended prenatal check-ups of the mother–child passport had been performed; healthy primiparae mothers of Austrian or Central European origin; term delivery (39th and 40th weeks of gestation); a minimum maternal age of 17 years at the time of giving birth; the delivery of a single infant without congenital malformations; no registered maternal diseases such as diabetes mellitus or nephropathy before and during pregnancy; no hypertension (BP < 150/90 mmHg); and no protein or glucose in the urine. Pregnancies resulting from IVF were also strictly excluded. Additionally, drug or alcohol abuse were defined as exclusion criteria, but this amounted to less than 0.5% of the mothers.

The Viennese Danube Hospital is one of the largest public birth clinics in Vienna. In general, pre-, peri- and postnatal care is highly developed in Austria. More than 40 years ago the so-called mother–child passport – a highly sophisticated monitoring system of pregnancy, and intrauterine and postnatal development – was developed. Seven prenatal check-ups starting at the 8th week of gestation and eight postnatal check-ups of the child between birth and the fourth year of life are provided free of charge. The prenatal examinations are mainly performed in the consulting rooms of gynaecologists or at the clinic where birth was scheduled to take place. Postnatal check-ups are carried out by paediatricians.

All data collected at the individual check-ups are documented at the hospital and in the mother–child passport, which belongs to the mother. A completed mother–child passport is rewarded by the government with a financial payment. The introduction of this pre- and postnatal monitoring system has reduced neonatal and child mortality dramatically in Austria (Waldhoer *et al.*, 1996). In the present study, data from three sonographic examinations (one at each trimester) and birth outcomes were analysed. All these sonographic examinations were carried out at the Danube hospital.

Prenatal examinations: fetal biometry

Gestational age was calculated as the number of weeks from the beginning of the last menstrual bleeding to the date of delivery (= duration of amenorrhoea). Fetal growth patterns were reconstructed from the results of the three ultrasound examinations.

The first examination took place at the 11^{th} or 12^{th} week of gestation (first trimester), the second at the $20^{th}/21^{th}$ gestational week (second trimester) and the third at the $32^{th}/33^{th}$ week of gestation (third trimester). Consequently the fetuses could vary in age up to at least 2 weeks at each trimester. Therefore the raw measurements were adjusted to a single gestation for each trimester separately before using them for statistical analyses.

The transabdominal ultrasound examinations were performed by a limited number of trained specialists (fewer than fifteen) using Voluson 730 and Voluson S6 (GE 8) ultrasonography. The following routine sonographic measurements, performed according to Hadlock's criteria (Hadlock *et al.*, 1982a,b,c), were documented. At the first scan (11^{th} or 12^{th} gestational week) crown–rump length was determined. At the second (20^{th} or 21^{th} gestational week) and third examinations (32^{th} or 33^{th} weeks of gestation) biparietal diameter, fronto-occipital diameter, head circumference, abdominal transverse diameter, abdominal anterior–posterior diameter, abdominal circumference and femur length were measured. Crown–rump length was defined as the distance between the top of the head (crown) to the bottom of the buttocks (rump). Femur length was measured from the greater trochanter to the lateral condyle. Biparietal diameter was defined as the distance from the proximal outer table to the distal outer table of the skull at the level of the thalamus. Fronto-occipital diameter follows a line extending from a point just above the root of the nose to the most prominent portion of the occipital bone. Head circumference is the measurement around the calvarium excluding soft tissues. Transverse and anterior–posterior abdominal diameters were taken at the level of the stomach and the bifurcation of the main portal vein into its right and left branches. Abdominal circumference was measured at the level of the liver and stomach, including the left portal vein at the umbilical region (Hadlock *et al.*, 1982a,b,c, 1984; Kurmanavicius *et al.*, 1999a,b; Snijders & Nicolaides, 1994; Abdella *et al.*, 2014).

Newborn characteristics

Immediately after birth the following parameters were taken directly from the newborn: birth weight in grams using a digital infant scale, birth length in centimetres using a standard measurement board for infants and head circumference in centimetres using a tape. The ponderal index (kg/m^3) of the newborn was calculated (Roje *et al.*, 2004). A low birth weight was defined as <2500 g and a high birth weight (macrosomia) as >4000 g, according to WHO recommendations (WHO, 1980).

Maternal parameters

Exclusively primiparae women aged between 17 and 48 years (mean = 28.3; SD = 5.6) were enrolled in the study. Besides, medical anamnesis, civil status and nicotine consumption levels of the pregnant women were obtained by interview at the first prenatal visit (8^{th} week of gestation). Nicotine consumption was assessed as follows: not smoking; 1–10 cigarettes per day; 11–20 cigarettes per day; and more than 20 cigarettes per day. Additionally the maternal somatometric parameters height and pre-pregnancy weight were collected at the first prenatal visit according to the recommendations of Knussmann (1988). Height was measured to the nearest 0.5 cm using a standard anthropometer. Pre-pregnancy weight was obtained by interview using the retrospective method. Additionally, body weight was measured to the nearest 0.1 kg on a balance beam scale. Since during the first 13 weeks of gestation an extremely small weight gain of only 1.7% has been reported in literature (Gueri *et al.*, 1982), a combination of the retrospective method and weight determination at the 8th week of gestation was used. Consequently, pre-pregnancy weight was calculated as the mean value of the retrospective estimated weight and the weight at the 8th week of gestation. Additionally, maternal weight was measured before delivery (at the end of pregnancy). The weight gain during pregnancy was calculated by subtraction of pre-pregnancy weight from body weight before delivery. Maternal pre-pregnancy weight status was determined by the body mass index (BMI in kg/m^2) using height and pre-pregnancy weight. To classify maternal weight status the cut-offs published by the WHO were used (WHO, 1995): underweight, BMI <18.50 kg/m^2; normal weight, BMI 18.50–24.99 kg/m^2; overweight, BMI 25.00–29.99 kg/m^2; obesity, BMI >30.00 kg/m^2.

Obstetric characteristics

Mode of delivery, spontaneous delivery versus Caesarean section and the intrauterine position of the infant at the time of delivery (head presentation, pelvic presentation) were documented. The most frequent indications for Caesarean delivery were fetal distress and dystocia. Caesarean sections on maternal request are not carried out at the Viennese Danube Hospital.

Statistical analysis

Statistical analyses were carried out using SPSS for Windows (Version 22). The Kolmogoroff–Smirnov test was performed in order to test somatometric variables for normal distribution. The results of this test indicated that normal distribution for all maternal as well as fetal and newborn parameters can be assumed. Partial correlations (maternal age and gestational week held constant) were calculated to test the correlations between maternal somatometric parameters and fetal biometry as well as newborn size. Multiple regression analyses were performed to test the associations between maternal height, pre-pregnancy weight status and fetal biometry adjusted for maternal age, nicotine consumption and fetal sex. Regression models included maternal height and pre-pregnancy weight status simultaneously. Multiple regression analyses were performed to test the associations between maternal height, pre-pregnancy weight status and gestational weight gain with newborn size, adjusted for nicotine consumption and newborn sex. All three maternal measurements were included simultaneously into the regression model. A *p*-value below 0.05 was considered statistically significant.

Results

Maternal characteristics

The maternal age, family status, smoking behaviour, height, pre-pregnancy weight status and gestational weight gain of the 4261 study women are presented in Table 1. The vast majority of the women (95.2%) were between the ages of 20 and 39 years when

Table 1. Maternal characteristics (descriptive statistics), $N = 4261$

Maternal characteristics	Mean (SD)	Range	*n* (%)
Civil status			
Unmarried			2011 (47.2%)
Married			2126 (49.9%)
No information			124 (2.9%)
Nicotine consumption during pregnancy			
Yes			643 (15.1%)
No			3618 (84.9%)
Maternal age	28.3 (5.6)	17.0–48.0	
Maternal age group			
<20 years			138 (3.2%)
20–29 years			2477 (58.1%)
30–39 years			1584 (37.2%)
≥40 years			62 (1.5%)
Height (cm)	165.9 (6.2)	143–189	
Pre-pregnancy weight (kg)	63.9 (13.3)	41–150	
Pregnancy weight gain (kg)	14.6 (5.6)	−3.0–52.0	
Pre-pregnancy BMI (kg/m^2)	23.19 (4.52)	17.83–52.73	

giving birth; 3.2% were younger than 20 years and only 1.5% were older than 40 years. About 50% of the sample women were married at the time they gave birth. Fifteen per cent continued smoking during pregnancy. The mean pre-pregnancy BMI of the women was 23.19 (SD 4.42), and ranged from 17.83 to 52.73 kg/m^2. The majority of the women (65.5%) corresponded to the WHO definition of normal weight. Only 7.3% were classified as underweight, but more than 25% were overweight or obese before pregnancy. The mean gestational weight gain was 14.6 kg (SD 5.6), and ranged from −3.0 kg to 52.7 kg.

Fetal and newborn characteristics

Fetal and newborn characteristics are presented in Table 2. The number of male newborns (50.4%) was slightly higher than that of females (49.6%). The majority of the newborns (90.0%) corresponded to the definition of normal weight (2500–3999 g). Only 1.7% were classified as small for gestational age (<2500 g), while 8.4% were macrosomic (≥4000 g). The rate of Caesarean section delivery was 15.9%. The vast majority showed a head presentation (94.7%), while only 5.7% showed a pelvic presentation.

Maternal somatic factors and fetal growth

In order to test the correlation patterns between maternal height and pre-pregnancy weight status and fetal biometry, partial correlations (with maternal age held constant) were calculated. As demonstrated in Table 3, maternal height correlated significantly positively from the first trimester onwards. Significant correlations were found with crown–rump length at the first trimester, with all fetal parameters at the second trimester

Table 2. Fetal and newborn characteristics (descriptive statistics), $N = 4261$

	Mean (SD)	Range	*n* (%)
Fetal characteristics			
Sex			
Male			2148 (50.4%)
Female			2113 (49.6%)
Crown–rump length (mm) (1.scan)	60.7 (6.9)	42.0–84.0	
Femur length (mm) (2.scan)	35.8 (1.9)	28.0–63.9	
Fronto-occipital diameter (mm) (2.scan)	67.1 (2.9)	53.8–99.5	
Biparietal diameter (mm) (2.scan)	52.9 (2.5)	42.8–84.9	
Head circumference (mm) (2.scan)	188.5 (7.2)	153.7–289.7	
Abdominal transverse diameter (mm) (2.scan)	49.1 (3.2)	36.2–81.1	
Abdominal anterior–posterior diameter (mm) (2.scan)	51.4 (3.8)	38.8–80.6	
Abdominal circumference (mm) (2.scan)	157.8 (8.9)	118.6–254.0	
Femur length (mm) (3.scan)	63.4 (2.7)	51.9 –73.0	
Fronto-occipital diameter (mm) (3.scan)	107.9 (4.7)	81.0–123.3	
Biparietal diameter (mm) (3.scan)	87.1 (3.4)	73.0–100.5	
Head circumference (mm) (3.scan)	306.6 (11.1)	261.9–344.5	
Abdominal transverse diameter (mm) (3.scan)	85.8 (5.2)	67.6–110.0	
Abdominal sagittal diameter (mm) (3.scan)	88.5 (5.6)	67.9–111.5	
Abdominal circumference (mm) (3.scan)	273.8 (13.4)	227.0–344.0	
Newborn characteristics			
Birth weight (g)	3385.9 (433.5)	1745–5110	
Birth length (cm)	50.7 (2.0)	37.0–60.0	
Ponderal index (kg/m^3)	2.58 (0.25)	1.86–8.74	
Head circumference (cm)	34.2 (1.4)	29.0–50.0	
Newborn weight status			
Low weight (<500 g)			71 (1.7%)
Normal weight (2500–3999 g)			3834 (90.0%)
Macrosomic (>4000 g)			356 (8.3%)

1.scan, 1st trimester scan; 2.scan, 2nd trimester scan; 3.scan, 3rd trimester scan.

and femur length as well as head parameters at the third trimester. No significant correlations could be observed between maternal height and fetal abdominal dimensions at the third trimester. Pre-pregnancy weight status correlated significantly positively with femur length and the fronto-occipital diameter at the second trimester and all fetal parameters at the third trimester. The results of the partial correlations were corroborated by those of the multiple regression analyses. As shown in Table 4, maternal height was significantly positively related to crown–rump length at the first trimester independent of maternal age and fetal sex. As shown in Table 5, maternal height was significantly positively related with all fetal parameters at the second trimester independent of fetal sex and maternal age, and femur length and the head parameters at the third trimester. Pre-pregnancy weight status was significantly positively associated with femur length at the second trimester and all fetal parameters at the third trimester.

Maternal somatic factors and newborn size

Maternal height, pre-pregnancy weight status and gestational weight gain correlated highly significantly with newborn birth weight, birth length and head circumference

Table 3. Correlations between maternal height, pre-pregnancy weight, pre-pregnancy BMI and fetal biometry[a]

	Height		Pre-pregnancy weight		Pre-pregnancy BMI	
Fetal biometry	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
First trimester						
Crown–rump length	0.03	0.039	0.02	ns	0.02	ns
Second trimester						
Femur length	0.06	<0.001	0.12	<0.001	0.11	<0.001
Fronto-occipital diameter	0.06	<0.001	0.06	<0.001	0.04	0.021
Biparietal diameter	0.05	0.004	0.01	ns	−0.01	ns
Head circumference	0.06	<0.001	0.04	0.007	0.02	ns
Abdominal transverse diameter	0.05	0.001	0.03	ns	0.01	ns
Abdominal anterior–posterior diameter	0.03	0.035	0.01	ns	−0.01	ns
Abdominal circumference	0.05	0.001	0.02	ns	−0.01	ns
Third trimester						
Femur length	0.14	<0.001	0.15	<0.001	0.11	<0.001
Fronto-occipital diameter	0.09	<0.001	0.08	<0.001	0.05	0.001
Biparietal diameter	0.16	<0.001	0.09	<0.001	0.05	0.002
Head circumference	0.14	<0.001	0.11	<0.001	0.06	<0.001
Abdominal transverse diameter	−0.01	ns	0.11	<0.001	0.12	<0.001
Abdominal anterior–posterior diameter	0.03	ns	0.09	<0.001	0.09	<0.001
Abdominal circumference	0.01	ns	0.13	<0.001	0.13	<0.001

[a]Partial correlation maternal age and gestational week (for each trimester separately) = constant.

Table 4. Association patterns between maternal age, stature, pre-pregnancy weight status, nicotine consumption and fetal sex with crown–rump length (dependent variable) at 11th to 12th weeks gestation using multiple regression analysis

	R^2	*B*	*p*-value	95% CI
Maternal age	0.06	0.04	0.040	(0.01, 0.08)
Height		0.04	0.041	(−0.03, 0.04)
Pre-pregnancy BMI		−0.04	ns	(−0.08, 0.01)
Nicotine consumption		−0.11	ns	(−0.73, 0.50)
Fetal sex		−0.70	0.001	(−1.13, −0.28)

B, regression coefficient; CI, confidence interval; ns, non-significant.

(see Table 6). These findings were corroborated by the results of the multiple regression analyses. Maternal height, pre-pregnancy weight status and gestational weight gain were significantly positively associated with all parameters of newborn size. A negative association was found between nicotine consumption and newborn size. Furthermore, female sex was significantly associated with smaller newborn dimensions (Table 7).

Table 5. Association patterns between maternal age, stature, pre-pregnancy weight status, nicotine consumption and fetal sex with fetal biometry at 20th/21th and 32th/33th weeks gestation using multiple regression analysis

	20th/21th weeks gestation				32th/33th weeks gestation			
	R^2	*B*	*p*-value	95% CI	R^2	*B*	*p*-value	95% CI
Dependent variable: biparietal diameter								
Maternal age	0.22	−0.01	ns	(−0.01, 0.01)	0.23	−0.01	ns	(−0.03, 0.01)
Height		0.02	0.005	(0.01, 0.03)		0.08	0.001	(0.07, 0.09)
Pre-pregnancy BMI		−0.01	ns	(−0.02, 0.01)			0.001	(0.02, 0.06)
Nicotine consumption		−0.03	ns	(−0.24, 0.18)		−0.58	0.001	(−0.87, −0.28)
Fetal sex		−1.04	0.001	(−1.19, −0.90)		−1.12	0.001	(−1.32, −0.92)
Dependent variable: fronto-occipital diameter								
Maternal age	0.19	.0.02	ns	(−0.03, 0.01)	0.19	−0.01	ns	(−0.03, 0.02)
Height		0.03	0.001	(0.02, 0.04)		0.08	0.001	(0.05, 0.09)
Pre-pregnancy BMI		0.03	0.007	(0.01, 0.05)		0.06	0.001	(0.03, 0.09)
Nicotine consumption		−0.05	ns	(−0.29, 0.20)		−0.71	0.001	(−1.12, −1.03)
Fetal sex		−1.03	0.001	(−1.20, −0.86)		−1.32	0.001	(−1.59, −1.03)
Dependent variable: head circumference								
Maternal age	0.24	−0.03	ns	(−0.07, 0.01)	0.24	−0.01	ns	(−0.07, 0.06)
Height		0.07	0.001	(0.04, 0.11)		0.25	0.001	(0.19, 0.30)
Pre-pregnancy BMI		0.04	ns	(−0.01, 0.08)		0.15	0.001	(0.08, 0.22)
Nicotine consumption		−0.09	ns	(−0.70, 0.50)		−2.05	0.001	(−3.00, −1.11)
Fetal sex		−3.25	0.001	(−3.66, −2.83)		−3.82	0.001	(−4.47, −3.17)
Dependent variable: abdominal transverse diameter								
Maternal age	0.11	−0.01	ns	−0.02, 0.02)	0.12	0.01	ns	(−0.03, 0.03)
Height		0.03	0.001	(0.02, 0.05)		−0.01	ns	(−0.03, 0.02)
Pre-pregnancy BMI		0.01	ns	(−0.01, 0.03)		0.13	0.001	(0.09, 0.17)
Nicotine consumption		−0.05	ns	(−0.33, 0.22)		−0.45	ns	(−0.91, 0.01)
Fetal sex		−0.57	0.001	(−0.76, −0.38)		−0.39	0.013	(−0.71, −0.08)
Dependent variable: abdominal anterior–posterior diameter								
Maternal age	0.13	0.03	0.002	(0.01, 0.06)	0.13	0.01	ns	(−0.03, 0.03)
Height		0.02	0.046	(0.00, 0.04)		0.02	ns	(−0.01, 0.05)
Pre-pregnancy BMI		−0.01	ns	(−0.03, 0.02)		0.12	0.001	(0.08, 0.15)
Nicotine consumption		−0.20	ns	(−0.53, 0.13)		−0.94	0.001	(−1.43, −0.46)
Fetal sex		−0.86	0.001	(−1.08, −0.63)		−0.63	0.001	(−0.97, −0.29)
Dependent variable: abdominal circumference								
Maternal age	0.15	0.05	0.046	(0.01, 0.10)	0.16	0.01	ns	(−0.08, 0.08)
Height		0.08	0.001	(0.04, 0.12)		0.03	ns	(−0.04, 0.09)
Pre-pregnancy BMI		0.01	ns	(−0.05, 0.07)		0.39	0.001	(0.31, 0.48)
Nicotine consumption		−0.48	ns	(−1.25, 0.29)		−2.25	0.001	(−3.42, −1.07)
Fetal sex		−2.27	0.001	(−2.80, −1.75)		−1.60	0.001	(−2.41, −0.79)
Dependent variable: femur length								
Maternal age	0.13	−0.01	ns	(−0.02, 0.01)	0.21	−0.01	ns	(−0.03, 0.01)
Height		0.02	0.001	(0.01, 0.03)		0.06	0.001	(0.05, 0.08)
Pre-pregnancy BMI		0.05	0.001	(0.03, 0.06)		0.07	0.001	(0.05, 0.08)
Nicotine consumption		−0.11	ns	(−0.27, 0.06)		−0.69	0.001	(−0.93, −0.47)
Fetal sex		0.12	0.034	(0.01, 0.23)		0.27	0.001	(0.11, 0.43)

B, regression coefficient; CI, confidence interval; ns, non-significant.

Table 6. Correlations between maternal height, pre-pregnancy weight and pre-pregnancy BMI with newborn size[a]

	Newborn weight		Newborn length		Newborn head circumference	
Maternal parameter	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
Height	0.19	<0.001	0.19	<0.001	0.17	<0.001
Pre-pregnancy weight	0.19	<0.001	0.16	<0.001	0.13	<0.001
Pre-pregnancy BMI	0.14	<0.001	0.11	<0.001	0.09	<0.001
End of pregnancy weight	0.27	<0.001	0.23	<0.001	0.18	<0.001
Pregnancy weight gain	0.21	<0.001	0.16	<0.001	0.13	<0.001

[a]Partial correlation maternal age = constant.

Table 7. Association between maternal parameters, nicotine consumption, newborn sex and newborn size using multiple regression analysis

	R^2	*B*	*p*-value	95% CI
Dependent variable: birth weight	0.39			
Maternal age		−4.28	0.001	(−6.64, −1.91)
Height		7.42	0.001	(5.28, 9.56)
Pre-pregnancy BMI		6.34	0.001	(5.35, 7.34)
Pregnancy weight gain		17.11	0.001	(14.84, 19.30)
Nicotine consumption		−193.71	0.001	(−229.51, −157.91)
Newborn sex		−135.65	0.001	(−160.33, 110.97)
Dependent variable: birth length	0.35			
Maternal age		−0.01	ns	(−0.02, 0.01)
Height		0.04	0.001	(0.03, 0.05)
Pre-pregnancy BMI		0.02	0.001	(0.02, 0.03)
Pregnancy weight gain		0.06	0.001	(0.05, 0.07)
Nicotine consumption		−0.81	0.001	(−0.98, −0.64)
Newborn sex		−0.68	0.001	(−0.79, −0.56)
Dependent variable: head circumference	0.32			
Maternal age		−0.01	ns	(−0.01, 0.01)
Height		0.03	0.001	(0.02, 0.03)
Pre-pregnancy BMI		0.01	0.001	(0.01, 0.02)
Pregnancy weight gain		0.03	0.001	(0.02, 0.04)
Nicotine consumption		−0.57	0.001	(−0.69, −0.46)
Newborn sex		−0.49	0.001	(−0.58, −0.41)

B, regression coefficient; CI, confidence interval; ns, non-significant.

Discussion

The present study examined the association between maternal height and pre-pregnancy weight status and fetal growth parameters during the first, second and third trimesters in 4261 singleton pregnancies taking place in Vienna, Austria. Furthermore, the relationship between maternal height, pre-pregnancy weight status as well as gestational weight gain and newborn size was analysed.

The study has certain limitations. The main shortcoming is that fetal biometry was taken only once per trimester. Furthermore, fetal measurements and newborn size parameters were taken by several different investigators (although all were well trained). The strength of the study is the large data set comprising fifteen fetal and three newborn measurements from 4261 children. However, this large sample size may result in some significant but small correlations. In this way the large sample size potentially weakens the results.

In general it could be shown that maternal height was significantly related to fetal growth parameters independent of maternal age, maternal nicotine consumption and fetal sex from the first trimester onwards. Maternal height correlated significantly with crown–rump length at the $11^{th}/12^{th}$ week of gestation, while in contrast no association between maternal pre-pregnancy weight status and fetal growth during the first trimester could be observed. This result corresponds to that of Sarris *et al.* (2010), who also found no significant association between maternal weight status and crown–rump length during the first trimester. These findings suggest a greater genetic and lesser environmental influence on growth patterns during the first trimester because maternal height reflects, above all, the genetic potential for growth (Wills *et al.*, 2010). Pre-pregnancy weight status, in contrast, can be interpreted as an indicator of environmental conditions before and during early pregnancy. The minor association between environmental conditions and growth during the first trimester may be due to the fact that the first trimester is characterized by an increase in cell numbers, the formation of embryonic tissues and organogenesis, while the embryo grows only slowly in length (Meire, 1986; Bogin, 1999).

The rate of growth of the fetus increases during the second trimester (Bogin, 1999). The present study found a statistically significant relationship between maternal height and all fetal parameters. Again, genetic factors, reflected in maternal height, were significantly related to all fetal growth parameters. Pre-pregnancy weight status, in contrast, was significantly related to femur length and the fronto-occipital diameter only. In particular, fetal abdominal dimensions were not found to be related to pre-pregnancy weight status. Consequently, intrauterine environmental factors – reflected by pre-pregnancy weight status – seem to play a minor role in fetal growth during the second trimester. This may be due to the fact that growth in length exceeds the growth in weight during the second trimester.

During the third trimester growth in fetus weight takes place at a relatively faster rate (Bogin, 1999) and the development and maturation of several physiological systems takes place preparing the fetus for the transition to extrauterine life. In this study maternal height was found to be significantly positively associated with femur length, and with the three fetal head parameters. In contrast, no significant association was found between maternal height and fetal abdominal dimensions. Pre-pregnancy weight status, however, was found to be significantly positively associated with femur length, the head dimensions and the three abdominal dimensions. This finding indicates that fetal growth during the third trimester is significantly associated with intrauterine environmental conditions. Maternal pre-pregnancy weight status and gestational weight gain are indicators of the energetic situation before and during pregnancy. Maternal undernutrition has adverse effects on fetal growth (Jeric *et al.*, 2013; Field *et al.*, 2015). Fetal growth depends mainly on the delivery of oxygen and nutrients across the placenta

(Aye *et al.*, 2013). The ability of the placenta to supply essential nutrients to the fetus depends on the nutritional status of the mother, utero-placental blood flow and the expression and function of the trophoblast nutrient transporter (Aye *et al.*, 2013). Recently evidence has emerged that the adipocyte-derived adiponectin plays a key role in the regulation of maternal, placental and fetal physiology. Adiponectin levels increase in early pregnancy (Mazaki-Tovi *et al.*, 2007) and decline over the second half of gestation (Catalano *et al*., 2006). It is assumed that high levels of adiponectin in early pregnancy enhance the maternal accretion of nutrients and lower levels of adiponectin in later gestation promote allocation of nutrients to the fetus (Aye *et al.*, 2013). Consequently adiponectin is thought to be a key factor in fetal growth regulation stimulated by maternal body fat, i.e. maternal BMI.

As for the association between maternal somatometrics and fetal growth patterns, the findings of the present study are only partly in accordance to those of previous studies. On the one hand the results are quite similar to those of Albouy-Llaty *et al.* (2011), who described a strong association between maternal BMI and fetal abdominal circumference, as well as a significant impact of maternal stature on fetal femur length. Furthermore, the positive association found between maternal stature as well as pre-pregnancy weight status and fetal head dimensions in the third trimester is quite similar to the findings of Goldenberg *et al.* (1993), who reported positive associations between head circumference at 31 weeks, 36 weeks and at birth. On the other hand, Wills *et al.* (2010) found only weak associations between maternal somatometrics and fetal dimensions. Their study population, however, consisted of rural Indian women, who were described as short, light and thin, while the present sample consisted exclusively of women of Central European origin. Additionally, more than 25% of these women were overweight or obese.

Newborn size, characterized by birth weight, birth length and head circumference, was found to be highly significantly related to maternal height, pre-pregnancy weight status and gestational weight gain. The positive impact of maternal height on newborn size is in accordance with the observation of Pickett *et al.* (2000), who reported that increasing maternal height was associated with increasing newborn weight. Furthermore, a significant association between gestational weight gain and newborn size was documented in the present study. In general, newborn size increased with increasing gestational weight gain independent of maternal age, pre-pregnancy weight status and maternal stature. This finding is in accordance with those of some previous studies, which yielded a strong relationship between low gestational weight gain and small for gestational age infants (Kirchengast & Hartmann, 1998, 2003; Siega-Riz *et al.*, 2009; Han *et al.*, 2011; Savitz *et al.*, 2011; Drehmer *et al*., 2013; Galjaard *et al.*, 2013). Furthermore, a positive influence of gestational weight gain on fetal growth was documented by Hinkle *et al*. (2015), who reported a significant impact of maternal weight gain on fetal growth and consequently newborn size.

From the results of the present study it can be concluded that a significant association between maternal size and fetal growth patterns is detectable from the first trimester onwards. Genetic factors reflected by maternal height are significantly associated with fetal growth patterns during the first and second trimester. Consequently fetal growth is accelerated among taller mothers during the first and second trimesters. During the third trimester environmental factors – reflected by maternal weight status – increase in importance for intrauterine growth. In general taller mothers and heavier mothers give birth to larger infants.

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