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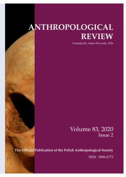

Caesarean sections are associated with sonographic determined fetal size from the second trimester onwards

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Abstract: Human birth represents a critical and life-threatening event in the life of mother and child and is therefore of special importance for anthropological as well as public health research.
Study aims: to analyze the association patterns between fetal biometry and delivery modes from the first trimester onwards.
In this electronic medical record-based study, a dataset of 3408 singleton term birth taking place at the Viennese Danube hospital in Austria. was analyzed. Fetal biometry was reconstructed by the results of three ultrasound examinations carried out at the 11th/12th, 20th/21th and 32th/33thweek of gestation. In detail, crown-rump length, biparietal diameter, fronto-occipital diameter, head circumference, abdominal transverse diameter, abdominal sagittal diameter, abdominal circumference, and femur length were determined. Birth weight, birth length and head circumference were measured immediately after birth. Four delivery modes were compared: spontaneous vaginal birth, instrumental vaginal birth, planned cesarean section and emergency cesarean section.
The total cesarean section rate was 10.2%. Fetal biometry and newborn size differed significantly between the four delivery modes. From the second trimester onward, head circumferences were significantly larger (p=0.005) among fetuses delivered by instrumental delivery or emergency cesarean section than among fetuses delivered by spontaneous vaginal birth. The fetal abdominal dimensions during the third trimester were significantly largest (p=0.001) among fetuses delivered by emergency cesarean section. In comparison to spontaneous vaginal delivery the risk to require instrumental delivery increased significantly with increasing fetal head dimensions at the second (p=0.019) and third trimester(p=0.032) independent of maternal somatic factors. The risk of emergency CS increased significantly with increasing head dimensions (p=0.030) as well as abdominal dimensions (p=0.001) at the third trimester and newborn size (p=0.002), also independently of maternal somatic factors.
In general, larger fetuses are on an increased risk of experiencing instrumental delivery or emergency caesarean section. This association between fetal size and delivery mode is detectable from the second trimester onwards.

Key words: fetal growth, sonography, newborn size, caesarean section, delivery mode

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Introduction

Human females experience painful and dangerous deliveries, which take much longer than in other mammals, even in nonhuman primates (Shipman 2013). Throughout human history, pregnancy and in particular childbirth, increased maternal and offspring mortality and had in this way an important impact on natural selection (Rosenberg 1992, Rosenberg and Trevathan 2018). Consequently, pregnancy and childbirth are seen as life threatening events and were focused on predominantly from a medical viewpoint. From a bioanthropological perspective however childbirth is not a disease per se but an essential part of female life history. Life threatening complications arising with childbirth are discussed as a consequence of evolutionary trends, typical of *Homo sapiens* (Krogman 1951, Washburn 1960, Wells et al. 2012, Warrener et al. 2015, Wells 2015, Rosenberg and Trevathan 2018).

Even today, several hundred thousand women die on account of pregnancy and childbirth every year and an even larger number of women suffer from long term health complications associated with parturition (Alkema et al. 2016). According to the World Health Organization (WHO), 2017 more than 800 women died every day from preventable causes associated with pregnancy and birth worldwide (WHO 2019). During our evolution and history, several cultural adaptations or coping strategies have been developed to reduce the risk of delivery (Rosenberg and Trevathan 2002, Rosenberg 1992, Trevathan 1993, Buck 2011, Rosenberg and Trevathan 2014). During the last century, surgical procedures such as cesarean sections (C-section) gain in importance (Todman 2007). There is no doubt, that C-section is a safe and life-saving surgical technique, which helps to reduce maternal and offspring mortality drastically (Gabbe and Holzmann 2001). Consequently, C-sections are one of the most frequently performed surgeries in women of reproductive age (Betran et al. 2016, Boatin et al. 2018). Currently, the average global rate of CS is about 18.6%, the prevalence however, differs markedly between different regions but also between different social strata within a country (MacFarlane et al. 2015, Boatin et al. 2018). The worldwide rising rates of C-sections however, are subject to growing concern (Vilar et al. 2007, Molina et al. 2015, Saeed et al. 2017). We have to be aware, that C-section rates increased up to more than 50% in several Latin American countries such as Dominican Republic (56.4%) or Brazil (55.6%) and in Near and Middle Eastern countries such as Egypt (51.8%), Iran (47.9%) or Turkey (47.5%) (Betran et al. 2016). High C-section rates are also found in western high-income countries. The critical discussion of "optimal" C-section rates is mainly due to the recommendations of the World Health Organization (WHO), which suggest that C-section rates above 10% make no further reduction of mortality and C-section rates above 15% may increase maternal morbidity and mortality (WHO 1985). Consequently, the World health organization recommends C-section rates of 10 to 15% (WHO 2009).

An increasing number of studies focused on the reasons of rising C-section rates. We have to distinguish between socially induced C-sections, which are carried out sometimes without any medical indication. Typical social factors enhancing C-section rates are high maternal socioeconomic status, private insurance, or maternal request without medical indication (Henderson et al. 2001; Marshall et al. 2011, Tarney 2014; Herstad et al. 2016). The most frequently cited biomedical reasons for C-sections are obstructed labor, fetal malposition, multiple gestation, problems with fetal heart rate, fetal macrosomia, cephalo-pelvic disproportion, short maternal stature height, maternal obesity and advanced maternal age (Chui et.al 2007, Kirchengast and Hartmann 2007, Poobalan et al. 2008, Machado 2012, Blomberg 2013, Declerq et al. 2015, Kara et al. 2015, Kirchengast and Hartmann 2019). In the present study, the impact of fetal biometry on delivery mode is focused on.

Recently dramatic changes of our life style seem to enhance the risk of C-sections (Kirchengast and Hartmann 2019). Diabetes and obesity rates among women of reproductive age increase worldwide (Kangura et al. 2017, Chen et al. 2018), a condition, which is associated with increased fetal size, particular macrosomia, i.e. a birth weight above 4000g (Catalano et al. 2012, Mitra et al. 2012). Increased fetal size, in particular large fetal head circumference, however is strongly associated with the risk of complications during delivery, such as obstructed labor, which may require an emergency C-section (Stock et al. 1994, Mocanu et al. 2000; Stotland et al. 2004, Lipschuetz et al. 2015). Consequently, a strong association between maternal obesity and C-section rates can be observed (Seligman et al.2006; Yamasato et al. 2016, Kirchengast and Hartmann 2017). A special problem represents the dual burden of malnutrition: Food shortages and others stress factors result in stunting and consequently a high frequency of short adult stature in many low-income populations. On the other hand, obesity rates rise, even in low and middle-income countries, resulting in a combination of short maternal stature and maternal obesity, a condition, which increases large fetal size, a disproportion between the fetus and the maternal pelvis and consequently birth complications and the risk of C-sections dramatically (Wells et al. 2018).

The concerns regarding excessive C-section rates mentioned above, plead for a detailed analysis of potential fetal biometric risk factors of C-sections in order to identify potential biometric parameters, which may help to predict the risk of C-sections as early as possible. Sovio and Smith (2017) demonstrated that ultrasound estimated fetal weight at 36th week of gestation, combined with maternal factors can identify women who are at increased risk of emergency C-section. Most studies focused on the association between ultrasound measured fetal head size parameters during the third trimester or even within one week of delivery and the risk of C-section (DeVries et al. 2016, Lipschütz et al. 2018, Yang et al 2017, Burke et al. 2012). De Vries et al. (2016) showed in their population-based cohort study a strong independent association between birth weight, neonatal head circumference and C-section rates. According to Lipschütz et al. (2018) a sonographic head circumference above 35cm measured within one week of delivery was an independent risk factor of unplanned C-section. Yang et al (2017) reported a significant association between fetal biometry in the third trimester and C-section. All these observations help to predict the risk of C-section based on fetal biometry, however exclusively fetal biometry of the late third trimester was included in the analyses.

The aim of the present study was to analyze the association patterns between fetal biometry and delivery modes from the first trimester onwards. We hypothesize, that increased fetal size from the first trimester onwards increase the risk of C-sections and instrumental delivery independently of maternal parameters (age, body height, weight status, gestational weight gain). In order to concentrate on the impact of fetal growth patterns on the mode of delivery a highly selective sample of births was analyzed. Multiple births, breech presentation, maternal age below 18 years, maternal diseases and assisted fertilization, which are well documented risk factors of C-sections, have been defined as exclusion criterions. In order to analyze newborns of similar gestational age only term births taking place at the 39^{th} and 40^{th} gestational week have been included.

Material and methods

Data set

In this electronic medical record-based study the data of 3408 singleton births were included. All births took place at one of the largest public birth clinics, the so-called Danube hospital, in Vienna, Austria between 2005 and 2013. The Danube hospital covered about 15% of all births taking place in Vienna. Since social insurance is mandatory for everybody living permanently in Austria, the great majority of women (81%) give birth at a public birth clinic. Pregnant women can choose freely that public birth clinic where delivery should take place. Less than 20% of births in Vienna take place at private birth clinics. These private birth clinics are frequented by women who have a private insurance additionally. Altogether, there are 8 public birth clinics in Vienna. The Danube hospital belongs to the three largest public birth clinics in Vienna. Between 2005 and 2013 a total of 17430 births took place at the Danube hospital, however 3408 births fulfilled the very strict inclusion criterions such as term birth (39^{th} and 40^{th} gestational week) of healthy nulliparous mothers of Austrian or Central European origin. Healthy was defined as the absence of HIV infection, gestational diabetes, nephropathy, alcohol abuse, high blood pressure. Furthermore, a normal head presentation of the fetus was a strict inclusion criterion, while irregular fetal positions such as breech presentation or transverse presentation were strict exclusion criterions, because both affect the mode of delivery. Any type of medically assisted reproduction such as IVF was excluded. That process yielded the final set of 3408 recorded births. The flowchart of the study population selection is presented in Figure 1.

This retrospective data collection was possible because of the standardized prenatal and postnatal care in Austria. All Austrian residents have social insurance that covers all medical costs in public hospitals. During the 1970s the sophisticated system of the so called “mother-child-passport” was introduced. Prenatal care usually starts at the 8^{th} week of gestation and includes seven check-ups during pregnancy. A minimum of three sonographic investigations of the fetus are mandatory (at the $11^{th}/12^{th}$ week, $21^{th}/22t^{h}$ week and at 32th/33th). Additionally, maternal health, diseases, smoking behavior and gestational weight gain are documented. Prenatal examinations are performed in consulting rooms of gynecologists or at the clinic where birth is scheduled to take place. After birth, the delivery mode, birth complications, duration of delivery, newborn size and Apgar scores are documented. Between birth and the fourth years of life eight postnatal check-ups of the child in pediatrician consulting rooms are mandatory. All pre- and postnatal check-ups are free of charge for Austrian residents. All data collected at the individual checkups are documented at the hospital and in the above passport, which belongs to the mother. Complete mother-child-passports are rewarded with a financial premium by the government.

Prenatal examinations – fetal biometry

Gestational age was calculated in terms of the number of weeks from the beginning of the last menstrual bleeding to the date of delivery (= duration of amenorrhea) and by two consecutive ultrasound examinations performed before the 12th week of gestation.

Fetal growth patterns were reconstructed by the results of three ultrasound examinations. The first examina-

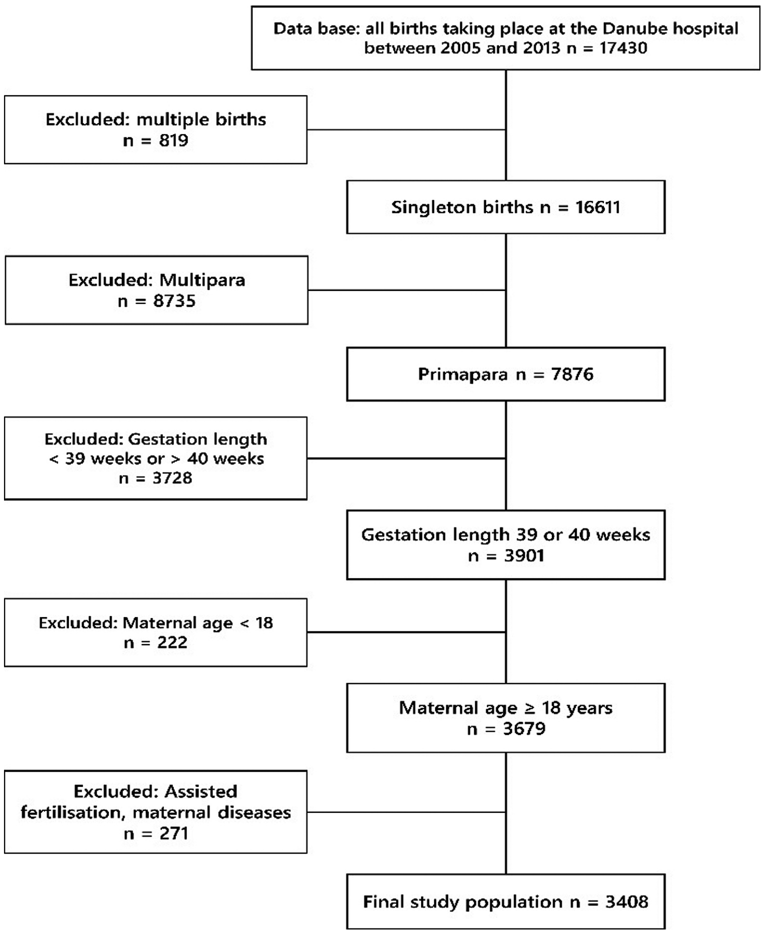

Fig. 1. Flowchart showing the inclusion and exclusion criteria used for extracting data

tion took place at the 11th or 12th week of gestation (first trimester), the second examination took place at the 20th/21th gestational week (second trimester) and the third examination at the 32th/33th week of gestation (third trimester). Consequently, the fetuses could vary in age up to at least two weeks at each trimester. Therefore, the raw measurements were adjusted to a single gestational week for each trimester separately before using them for statistical analyses. All transabdominal ultrasound examinations were performed by a limited number of trained specialists (<15 examiniers) 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 (11th or 12th gestational week) crown-rump length was determined. At the second (20th or 21th gestational week) and the third examination (32th or 33th week of gestation) biparietal diameter, fronto-occipital diameter, head circumference, abdominal transverse diameter, abdominal sagittal 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 sagittal 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 calculated (Hadlock et al. 1982a,b,c; Hadlock et al. 1984; Kurmanavicius et al. 1999a,b; Snijders and Nicolaides 1994; Abdella et al 2014).

Newborn characteristics

Immediately after birth the following parameter were directly taken from the newborn: birth weight in grams using a digital infant scale, birth length in centimeters using a standard measurement board for infants and head circumference in centimeters using a tape. A low birth weight was defined as < 2500g, a high birth weight (macrosomia) as >4000g according to the recommendations of the WHO (2009).

Maternal parameters

Exclusively nulliparous women ageing between 18 and 48 years (mean=28.1; SD= 5.3) were enrolled in the present study. Beside medical anamnesis, family status and nicotine consumption of the pregnant women were obtained by interview at the first prenatal visit (8th week of gestation). Nicotine consumption was assessed as follows: not smoking, 1 to 10 cigarettes per day, 11 to 20 cigarettes per day and more than 20 cigarettes per day. Additionally, the following maternal somatometric parameters were collected according to the recommendations of Knussmann (1988) at the first prenatal visit: Height and pre-pregnancy weight. Height was measured to the nearest 0.5cm using a standard anthropometer. Pre-pregnancy weight was obtained by interview using the retrospective method. Additionally, body weight was measured to the nearest 0.1kg on a balance beam scale. Based on the literature, the first 13 weeks of gestation involve an extremely small weight gain of only 1.7% (Gueri et al. 1982). Consequently, pre-pregnancy weight was calculated as the mean value of the reported weight and the weight at the 8^{th} 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 means of the body mass index (BMI) kg/m^2 using height and pre-pregnancy weight. To classify maternal weight status, the cut-offs published by the WHO (2000) were used: underweight = BMI < 18.50 kg/m^2; normal weight = BMI 18.50 kg/m^2 to 24.99 kg/m^2; overweight = BMI 25.00 kg/m^2 to 29.99 kg/m^2; obese = BMI > 30.00 kg/m^2

Obstetrical characteristics

The following obstetric characteristics were recorded: Delivery mode, i.e. spontaneous vaginal delivery, instrumental delivery (vacuum extraction), planned caesarean section and unplanned or emergency caesarian section. All planned caesarean sections were carried out exclusively for medical reasons. In the present study, the main reasons for planned caesarean sections were cephalo-pelvic disproportion (diagnosed by sonography), adverse child presentation or placenta previa. Caesarean sections upon maternal request without any medical indication were not performed at the Danube Hospital. The most frequent indications for emergency caesarean delivery were fetal distress and obstructed labor.

Statistical analysis

For statistical analyses SPSS for Windows (version 24.00) were used. Group differences were tested by Duncan analyses with Bonferroni corrections and χ^2. Odds ratios have been calculated to test the risk of experiencing instrumental vaginal delivery or C-sections of small for gestational weight newborns (<2500g) as well as macrosome newborns (>4000g) in comparison to normal weight ones (2500–4000g). To reduce the high number of fetal biometry variables, factor analyses (varimax rotation) were carried out. Binary logistic regression analyses using backward elimination method (rejection criterion was p-value > 0.05) were carried out to test the risk of experiencing instrumental vaginal delivery or C-sections in comparison to spontaneous vaginal births. Results of regression analyses have been corrected for maternal somatometric parameters (stature height, prepregnancy weight status), maternal age and nicotine during pregnancy. Fetal measurements were standardized for gestational age. $P < 0.05$ was considered as statistically significant.

Results

Maternal characteristics

Table 1 summarizes maternal age and maternal somatic characteristics. Additionally, information regarding nicotine consumption is provided. Mean age at first birth was 28.1 years. 85% of the mothers did not smoke during pregnancy. About 65% of the women correspond-

Table 1. Maternal characteristics (descriptive statistics)

Maternal characteristics	mean (SD)	range	n/(%)
Maternal age (yrs)	28.10 (5.40)	18–48	
Nicotine consumption during pregnancy			
no			2897 (85.0%)
yes			511 (15.0%)
Body height (cm)	165.80 (6.30)	148–188	
Prepregnancy weight (kg)	63.90 (13.40)	41.0–150.5	
End of pregnancy weight (kg)	78.50 (13.90)	48.5–149.1	
Gestational weight gain (kg)	14.60 (5.40)	−8.1–52.0	
Prepregnancy body mass index (kg/m^2)	23.24 (4.56)	16.83–52.73	
< 18.50 kg/m^2			245 (7.2%)
18.50–24.99 kg/m^2			2229 (65.4%)
25.00–29.99 kg/m^2			614 (18.0%)
≥ 30.00 kg/m^2			320 (9.4%)

ed to the definition of normal weight before pregnancy. 18.0% were classified as overweight, 9.4% as obese. Only 7.2% of the mothers were underweight before pregnancy. Gestational weight gain was generally high (x=14.6 kg, SD = 5.4). The highest gestational weight gain recorded was 52 kg. Few women however lost weight during pregnancy.

Fetal and newborn characteristics

The number of male newborns (n=1729; 50.7%) was slightly higher than that of female ones (n=1680; 49.3%). Fetal biometry during first, second and third trimester and newborn somatometrics are presented in Table 2. Data concerning newborn weight status revealed that 90.2% of the newborns corresponded to the definition of normal weight. Only 1.6% of the newborns were classified as low weight (< 2500g), while 8.2% were classified as macrosome, i.e. the birth weight exceeded 4000 g.

To reduce the high number of fetal and newborn biometric parameters, and to obtain more information about the structure of the fetal biometric data, a factor analysis of all 18 fetal as well as newborn biometric variables was computed. After varimax rotation, the factor analysis yielded seven factors with an Eigenvalue above 1.0. Factor 1 with an Eigenvalue 5.27 can be interpreted as a "3.trimester head factor (3THF)", higher loadings (0.74–0.95) were found for the head dimensions (biparietal diameter, fronto-occipital diameter and head circumference) at the third scan at 32th/33th gestational week. Factor 2 with an Eigenvalue 2.19 can be classified as "2.trimester head factor (2THF)" higher loadings (0.79–0.96) were found the head dimensions (biparietal diameter, fronto-occipital diameter and head circumference) at the second scan at 21st/22th gestational week. Factor 3 (Eigenvalue 2.03) can be described as a "newborn size factor" factor. Higher Loadings (0.76–0.87) were found for birth weight, birth length and head circumference. Factor 4 with an Eigenvalue of 1.36 is a "2.trimester abdominal factor (2TAF)". Highest loadings (0.74–0.97) were found for the abdominal dimensions (abdominal transverse diameter, the abdominal sagittal diameter and the

Table 2. Fetal characteristics (descriptive statistics)

Fetal biometry	Mean (SD)	range	n (%)
First trimester			
Crown rump length (mm)	60.2 (8.1)	40.0–85.0	
Second trimester			
Biparietal diameter (mm)	52.9 (2.4)	42.8–63.5	
Fronto-occipital diameter (mm)	67.1 (2.7)	54.1–90.1	
Head circumference (mm)	188.4 (6.7)	153.7–227.1	
Abdominal transverse diameter (mm)	49.1 (3.1)	36.2–60.2	
Abdominal sagital diameter (mm)	51.3 (3.7)	39.6–66.8	
Abdominal circumference (mm)	157.6 (8.6)	118.6–193.4	
Femur length (mm)	35.7 (1.8)	28.2–42.4	
Third trimester			
Biparietal diameter(mm)	86.9 (3.4)	73.0–100.5	
Fronto-occipital diameter (mm)	107.7 (4.6)	81.0–123.3	
Head circumference (mm)	306.2 (10.9)	244.9–344.5	
Abdominal transverse diameter (mm)	85.9 (5.2)	67.6–110.0	
Abdominal sagital diameter (mm)	88.7 (5.5)	70.0–111.5	
Abdominal circumference (mm)	274.2 (13.4)	228.7–344.0	
Femur length (mm)	63.4 (2.6)	54.0–73.0	
Newborn size			
Birth weight (g)	3391.9 (428.3)	1745–5110	
Birth length (cm)	50.7 (1.9)	37.0–58.0	
Head circumference (cm)	34.2 (1.3)	29.0–43.0	
Newborn weight status			
Low birth weight <2500g			55 (1.6%)
Normal birth weight 2500–3999g			3073 (90.2%)
Macrosomia >4000g			280 (8.2%)

abdominal circumference) of the 2.scan at 20th/21th gestational week. Factor 5 with an Eigenvalue of 1.29 can be described as a 3.trimester abdominal factor (3TAF)". Highest loadings (0.74–0.96) were found for the abdominal dimensions (abdominal transverse diameter, the abdominal sagittal diameter and the abdominal circumference) of third scan during third trimester at 32th/33th gestational week. Factor 6 with an Eigenvalue of 1.09 is "femur length factor (FLF)", with higher loadings (0.76 – 0.80) for femur length of the second and third scan. The seventh factor with an Eigenvalue of 1.023 is the "crown-rump length factor (CRLF)". A higher loading (0.91) was found for the crown-crump length of the first scan /11th/12th gestational week only.

Delivery mode

The majority of the enrolled women experienced a spontaneous vaginal delivery (82%). Vacuum extraction was performed among 7.1% of the women. The total cesarean section rate was 10.2%. The vast majority of the CS were unplanned (88.2%). 1.2% of all deliveries were planned CS, while 9.0% of the deliveries required emergency CS.

Delivery mode and fetal characteristics

The mode of delivery differed significantly between male and female offspring. Female newborns experienced spontaneous vaginal delivery more often than their male counterparts (85.1% vs. 80.3%). In comparison to spontaneous vaginal birth, the risk to experience instrumental delivery, i.e. vacuum extraction as well as emergency CS was significantly higher among male newborns (see Table 3). The risk to experience a planned CS in comparison to spontaneous vaginal birth, however, was higher among female newborns.

Furthermore, fetal as well as newborn biometry were significantly associated with delivery mode. Spontaneous vaginal delivery occurred among 69.1% of low weight newborns (<2500g), among 71.8% of macrosome newborns (>4000g) and among 83.9% of normal weight ones (2500–4000g). The frequency of emergency CS was significantly higher (p=0.001) among low weight newborns (24.0%) as well as among macrosome newborns (19.9%) in comparison to normalweight ones (8.7%). The frequency of planned CS did not differ significantly between normalweight (1.5%) and macrosome newborns (1.5%). Low weight newborns however showed the significantly (p=0.04) highest rate of planned CS (5.0 %). The rate of instrumental delivery was highest among macrosome newborns (11.5%) and lowest among low weight newborns (7.3%) (see Table 4). 7.6% of normal weight newborns experienced instrumental delivery.

Table 5 presented fetal and newborn biometry according to delivery mode. During first trimester, crown-rump length did not differ significantly between the four delivery modes. During second trimester, head circumference and biparietal diameter were significantly larger among fetuses delivered via vacuum extraction and emergency CS than fetuses experiencing spontaneous vaginal delivery. Fetuses delivered via emergency CS showed the highest abdominal dimensions during second trimester, the group differences between the modes of delivery however, were not of statistical significance. During the third trimester fetuses delivered via emergency CS showed the significantly largest head as well as abdominal dimensions. Further-

Table 3. Risk of instrumental delivery, planned section and emergency section according to newborn sex (spontaneous vaginal births are the reference group)

	male	OR (95% CI)	female	OR (95% CI)	Sign. *p*-value
Instrumental delivery	8.5%	1.23 (1.11–1.37)	5.7%	0.77 (0.66–0.91)	0.001
Planned section	0.8%	0.71 (0.47–1.07)	1.7%	1.28 (1.01–1.60)	0.030
Emergency section	10.4%	1.19 (1.08–1.32)	7.6%	0.82 (0.71–0.94)	0.002

Table 4. Risks of instrumental delivery, planned section and emergency section among low weight and macrosome newborns (normal weight newborns are the reference group)

	Low weight (<2500g)	OR (95% CI)	Macrosomia (> 4000g)	OR (95% CI)
Instrumental delivery	7.3%	0.96 (0.29–3.07)	11.5%	1.51 (1.02–2.22)
Planned section	5.0%	3.44 (0.86–13.79)	1.5%	1.01 (0.34–3.03)
Emergency section	24.0%	3.21 (1.69–6.05)	19.9%	2.24 (1.76–3.11)

Table 5. Fetal biometry according to mode of delivery (Duncan Analyses, Bonferroni corrections)

	Spontaneous vaginal delivery mean (SD)	instrumental delivery mean (SD)	planned section mean (SD)	emergency section mean (SD)	Significance *p*-value
1.trimester					
Crown-rump length (mm)	60.2 (8.1)	60.6 (8.3)	60.4 (7.0)	60.3 (7.9)	0.864
2. trimester					
Biparietal diameter (mm)	52.9 (2.4)[bd]	53.3 (2.4)[a]	52.6 (2.6)	53.0 (2.4)[a]	0.035
Frontooccipital diameter (mm)	66.9 (2.8)	67.3 (2.7)	66.4 (3.1)	67.3 (2.5)	0.137
Head circumference (mm)	188.2 (6.7)[bd]	189.5 (6.9)[a]	186.9 (7.9)	189.1 (6.6)[a]	0.005
Abdominal transverse diameter (mm)	49.0 (3.1)	49.2 (3.1)	48.8 (3.0)	49.4 (3.2)	0.141
Abdominal sagittal diameter (mm)	51.3 (3.7)	51.4 (3.6)	51.2 (3.8)	51.5 (3.8)	0.597
Abdominal circumference (mm)	157.5 (8.6)	158.0 (8.5)	157.1 (8.9)	158.6 (8.9)	0.159
Femur length (mm)	35.7 (1.8)	35.8 (1.8)	35.7 (1.6)	35.7 (1,9)	0.950
3.trimester					
Biparietal diameter(mm)	86.9 (3.3)[bd]	87.5 (3.9)[a]	87.3 (2.9)	87.5 (3.5)[a]	0.001
Frontooccipital diameter (mm)	107.6 (4.6)[d]	108.2 (4.8)	106.9 (4.1)	108.4 (4.3)[a]	0.012
Head circumference (mm)	306.9 (10.8)[bd]	307.7 (12.2)[a]	305.8 (9.8)	308.3 (10.6)[a]	0.001
Abdominal transverse diameter (mm)	85.7 (5.2)[d]	86.1 (5.3)[d]	86.5 (4.9)	87.3 (5.7)[ab]	0.001
Abdominal sagittal diameter (mm)	88.5 (5.4)[d]	88.7 (5.9)[d]	88.4 (6.0)	89.9 (5.7)[ab]	0.001
Abdominal circumference (mm)	273.7 (13.1)[d]	274.7 (14.6)[d]	274.6 (13.2)	278.4 (13.4)[ab]	0.001
Femur length (mm)	63.3 (2.6)	63.5 (2.7)	63.6 (2.9)	63.5 (2.7)	0.590
Newborn size					
Birthweight (g)	3380.8 (416.9)[d]	3431.4 (435.8)	3292.7 (462.5)[d]	3476.6 (504.2)[a c]	0.001
Birth length (cm)	50.7 (1.9)[d]	50 9 (2 3)	50.4 (2.1)	51.2 (2.3)[a]	0.001
Head circumference (cm)	34.1 (1.3)[d]	34.4 (1.4)	34.2 (1.4)	34.5 (1.3)[a]	0.001

Legend: a – significantly different from spontaneous vaginal delivery, b – significantly different from instrumental delivery, c – significantly different from planned section; d – significantly different from emergency sectio).

more, the newborns delivered via emergency CS were significantly larger, heavier and showed significantly higher head circumferences than newborns delivered vaginally or by planned caesarean section (Table 5).

The results of the ANOVA were corroborated by binary logistic regression analyses. (stepwise backward elimination method) In comparison to spontaneous vaginal delivery the risk to require instrumental delivery increased significantly with increasing 2. and 3.trimester head factors, newborn size, and maternal age. Increasing maternal body height reduced the risk of instrumental delivery significantly. The risk of experiencing planned caesarean section was not associated significantly with fetal biometry. Increasing maternal age, prepregnancy body mass index and gestational weight however increased the risk of planned CS. Increasing maternal body height, in contrast, reduced the risk of planned CS significantly. The risk of emergency CS increased significantly with increasing third trimester head factor, third trimester abdominal factor and newborn size factor. Furthermore, a significantly positive association between emergency CS and maternal age, prepregnancy body mass index, gestational weight gain, and nicotine consumption was found. Increasing maternal body height, however decreased the risk of experiencing emergency CS significantly (Table 6).

Table 6. Maternal and offspring characteristics and delivery mode Spontaneous vaginal delivery versus instrumental delivery planed CS and emergency CS. Binary logistic regression analyses

	Coeff B	Sign	Exp(B)	95% CI
Dependent variable: delivery mode	Vaginal delivery vs instrumental delivery (VD =1; VE =2))			
Head factor 2	0.18	0.010	1.19	1.04–1.36
Head factor 1	0.20	0.003	1.22	1.07–1.39
Newborn size factor	0.16	0.023	1.17	1.02–1.35
Maternal age	0.05	0.000	1.05	1.02–1.08
Maternal body height	−0.04	0.001	0.96	0.94–0.98
constant	2.73	0.142	15.39	
	Vaginal delivery vs planned CS (VD = 1; planned CS =2)			
Maternal age	0.13	<0.001	1.14	1.08–1.21
Maternal body height	−0.05	0.040	0.95	0.90–0.99
Prepregnancy BMI	0.09	0.002	1.09	1.03–1.15
Gestational weight gain	0.05	0.050	1.05	0.99–1.11
constant	−2.23	0.593	0.11	
	Vaginal delivery vs emergency CS (VD =1; emergency CS =2)			
Head factor 2	0.16	0.012	1.18	1.04–1.33
Newborn size factor	0.23	<0.001	1.26	1.11–1.44
Abdominal factor 2	0.21	0.001	1.23	1.08–1.39
Maternal age	0.09	<0.001	1.09	1.06–1.12
Maternal body height	−0.06	<0.001	0.94	0.92–0.96
Nicotine consumption	0.45	0.011	1.57	1.11–2.22
Prepregnancy BMI	0.08	<0.001	1.09	1.06–1.11
Gestational weight gain	0.04	0.001	1.04	1.02–1.06
constant	1.97	0.265	7.14	

Discussion

In the present study the association between ultrasound measured fetal biometry parameters and delivery mode was tested in a large sample containing data of 3408 singleton pregnancies taking place in Vienna, Austria. Despite of the large number of cases, the study has some limitations, such as that sonographic examination was carried out by different, however well-trained investigators. We are aware, that the estimation of fetal biometry by different gynecologists represents a weakness of the study, however data have been collected over 9 years from 2005 to 2013. Therefore, examiners changed during such a longtime. Another shortcoming represents the fact, that sonographic examinations have been carried out only once per trimester. This was due to that only routine examinations according to the Austrian Mother-Childhood Passport were included in the study. Despite of these limitations the strength of present study is the large sample size and the high number of fetal and newborn parameters. Furthermore, exclusively operative deliveries with a clear medical indication (such as fetal distress, cord prolapse, failure to progress in labor, cephalon-pelvic disproportion) were included in the present sample because C-sections upon maternal request are not performed at the Viennese Danube Hospital.

As described in the introduction and the methods section, the sample analyzed in the present study was a highly selective one. Only singleton term births of healthy primaparae mothers older than 17 years have been included. The reason for this selection was to exclude many typical indications of C-sections because we tried to focus on the association between fetal biometry and delivery mode. More than 80% of these women experienced spontaneous vaginal deliveries. Around 7 % of the women experienced an instrumental vaginal delivery, i.e. vacuum extraction. This rate of instrumental vaginal delivery is slightly higher than the Austrian rate of instrumental vaginal delivery at the time of investigation. Between 2005 and 2013 the rate of instrumental vaginal delivery ranged between 5.2% and 5.9% (Statistik Austria 2019). The C-section rate of the present sample was 10.2%, this is clearly significantly lower than the C-section rate in Austria at the time of investigation. From 2005 to 2013, the C-section rate increased in Austria from 24.4% to 29.3%, in Vienna an increase from 23.6% to 29.6% occurred (Statistik Austria). In 2019, the C-section rate in Austria was 29.4%. The low rate of C-sections in the present study is mainly due to the strict inclusion and exclusion criterions, but also due to the policy to reduce unnecessary C-sections in public hospitals in Vienna (Vienna policy statement on spontaneous birth). C-sections should only be performed if there is a medical indication. The Danube hospital belongs to the public hospitals and covers about 15% of all births taking place in Vienna. Around 2300 births take place there every year. Patients of the Danube hospital do not differ from those of the other public hospitals. The patients belong to all social strata of the Viennese society because even private patients are attending this birth clinic. Consequently, concerning the patient collective the Danube hospital is representative for Viennese public birth clinics. The C-section rate of the Danube hospital is with 19% markedly lower than that of the other public birth clinics in Vienna, where C-section rates ranges from 24% up to 35.4%. Only the birth clinic of the Medical University of Vienna shows a C-section rate of 52.5%. This is mainly due to the fact, that this clinic specializes in pregnancies and births with complications.

The predictive value of ultrasound measured fetal biometry for C-section risk have been analyzed in several nearly exclusively medical studies. The majority of studies however, considered fetal biometry at the end of pregnancy (Stock et al. 1994, Al Housseini et al. 2009, Peregrine et al. 2006, Tan et al. 2006, Kim et al. 2010), and did not focus on fetal growth patterns during first or second trimester. In the present study, however fetal biometry was assessed at the first, second and third trimester. In a first step, fetal biometry was compared between four different delivery modes, spontaneous vaginal delivery, instrumental delivery requiring vacuum extraction, planned C-section and unplanned or emergency C-section. As to be expected crown-rump length taken at the 11th or 12th week of gestation was not related significantly with the modes of delivery. Consequently, fetal growth during first trimester has no significant influence on birth complications requiring instrumental or operative delivery. At the second trimester (20th or 21th gestational week) however, biparietal diameter and head circumference differed significantly between the four delivery modes. Fetuses experiencing instrumental delivery and emergency C-sections showed significantly larger head dimensions, than fetuses experiencing spontaneous vaginal deliveries and planned C-sections. During third trimester, at 32th or 33th week of gestation fetuses experiencing emergency C-sections showed the significantly highest head as well as abdominal dimensions, followed by fetuses experiencing instrumental deliveries. According to the results of the binary logistic regression analyses, head size at the second and third trimester were significantly independently associated with an increased risk of experiencing instrumental delivery. Furthermore, the risk of experiencing emergency C-section was significantly increased with increasing head and abdominal size during the third trimester. Furthermore, the present study revealed a significant association between the risk of instrumental delivery as well as emergency C-section and newborn sex. In detail, the risk of experiencing instrumental delivery or C-section was higher among male offspring. Male offspring however, is larger from the first trimester onward (Davies et al. 1993, Melamed et al. 2013, Kirchengast et al. 2016).

In case of head dimensions, the present study adds to the growing body of evidence that fetal head size plays a significant role in progress of labor and consequently fetal head affects the delivery mode. Several studies have focused on the association between fetal head size and delivery mode (Bardin et al.2016). In general, the impact of fetal or neonate head dimensions on obstetric outcomes was highlighted (Lipschuetz et al. 2015, Valsky et al. 2009; 2016; deVries et al. 2016, Ooi et al. 2015). The impact of fetal head size on delivery mode is many due to the fact that the fetal head is directly interfacing with the maternal pelvis (Lipschuetz et al. 2018). In general, *Homo sapiens* is characterized by large head and brain size relative to body size. This is especially true of fetuses and neonates. There is a well-known evolutionary trend towards birthing relatively large infants from the Genus Australopithecus onwards (DeSilva 2011). Human mothers give birth to infants of about 6% of their body mass, chimpanezees in contrast, deliver offspring with approximately 3% of their body mass (DeSilva 2011). The assumed evolutionary advantage of larger fetuses however leads to a risky childbirth. During delivery, fetal heads are close to the size of the maternal birth canal (Rosenberg and Trevathan 2002). A large neonate head has a tight fit as the infant passes through the bony birth canal (Rosenberg and Trevathan 2002, Rosenberg 1992, Trevathan 1993, Rosenberg and Trevathan 2014). This cephalo-pelvic disproportion is part of our evolutionary heritage and makes childbirth complicated (Rosenberg 1992). Consequently, the impact of neonatal head size on delivery mode was analyzed in the majority of studies (Bardin et al. 2015; Ooi et al. 2015). In the majority of studies however, fetal head size was mainly estimated shortly before birth. Mujugira et al. (2013) demonstrated that a neonatal head circumference above 37cm was associated with double rate of operative delivery as compared to neonates with a head circumference of 34 cm. Ooi et al. (2015) reported similar results. In detail, a fetal head circumference above 35cm measured at the onset of labor, was predictive of C-sections (Ooi et al, 2015). In contrast to those studies mentioned above, in the present the impact of fetal size parameters on delivery mode from the first trimester onwards was tested. As pointed out above, we found a significant association between fetal head size and delivery mode from the 21th/22th gestational week onwards. During the third trimester not only head dimensions, but also abdominal dimensions were significantly associated with the delivery mode. Fetal abdominal size is a good indicator of fetal weight and fat deposition (Lee et al. 2009). During the third trimester growth in 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 extra-uterine life. Consequently, abdominal dimension gain in importance. Burke et al. (2017) reported a significant association between fetal abdominal circumference and delivery mode. In this study, the impact of fetal head circumference, fetal abdominal circumference but also maternal parameters (body mass index, age and body height) on delivery mode was tested. The risk of C-section increased with increasing fetal head circumference, abdominal circumference, maternal body mass index and maternal age, but decreased with increasing maternal body height (Burke et al. 2017). These results are very similar to that of the present study. We also included maternal parameters in binary logistic regression analyses and found the same associations as Burke et al. (2017). The significant associations between maternal parameters and delivery mode have been proved in several studies before (Yamamoto et al. 2016; Sovio and Smith 2017, Kirchengast and Hartmann 2007, 2017, 2019). Increasing maternal age, and decreasing maternal body height were significantly associated with an increased risk of instrumental delivery, planned CS and emergency CS. Increasing maternal prepregnancy BMI and gestational weight gain increased the risk of planned CS and emergency CS, too. The risk of emergency CS was also positively associated with nicotine consumption during pregnancy. According to the present results, maternal parameters have an independent effect on the mode of delivery. This observation is in accordance with those of several previous studies, which showed that maternal obesity but also maternal short stature are risk factors for C-sections (Kirchengast and Hartmann 2007, 2017). Maternal somatic parameters however, are also significantly associated with fetal growth patterns and newborn size (Albouy-Ilaty et al. 2011, Ay et al. 2009, Dietz etal al 2009, Kirchweger et al. 2018, Pölzlberger et al. 2017). The effect of maternal age on fetal growth and newborn size however, is not a linear one, but a u-shaped on. According to Kirchweger et al. (2018), largest dimensions of fetuses and newborns are found among mothers ageing between 20 and 35 years, while younger mothers and older mothers showed smaller newborns and fetuses. Therefore, the positive association between maternal age and C-section rates and instrumental delivery rates cannot be explained by a positive association between maternal age and fetal growth. Increasing maternal age may be seen as an independent risk factor for birth complications. The negative association between maternal body height and an increased risk of CS may be explained by maternal- fetal disproportion such as a too narrow pelvis, and newborn size (Kirchengast and Hartmann 2007). On the other hand, maternal parameters such as prepregnancy body mass index and gestational weight gain are associated with increased fetal size and may be in this way associated with an increased risk of C-sections. This effect was shown in the present study too. The main difference between the present study and that of Burke et al (2017) was the time of taking ultrasound measurements. Burke et al. (2017) performed ultrasound examination after 39 completed weeks and before 40 weeks and 6 days. With other words, fetal parameters have been taken shortly before birth.

While larger head size and abdominal dimensions increased the risk of instrumental vaginal delivery and emergency c-sections, planned c-sections were not significantly associated with increased fetal biometry. In contrast, planned c-sections were significantly associated with lower birth weight. In particular, small for gestational age newborn (<2500g) had a significantly increased risk to be delivered via planned or emergency c-sections. This significantly increased rate of c-sections among small for gestational age newborn may be due to the fact that small for gestational age newborn show an increased risk of morbidity and mortality (Boers et al. 2011). Therefore, c-sections are performed more frequently among small for gestational age newborns (Ludvigsson et al. 2018, Simoes et al. 2016), although several authors found no sufficient evidence to recommend planned c-sections in pregnancies of small for gestational age fetuses because no reduction of perinatal and postnatal morbidity and mortality could be proved. In the present study however, only 55 newborns, i.e. 1.6% of the whole sample corresponded to the definition of small for gestational age (<2500g). Therefore, the small for gestational age segment of the present study is not representative.

To sum up the results of the present study, increased fetal size increases the risk of instrumental vaginal delivery but also of emergency C-sections. In particular, we could show that head size was associated with delivery mode from the second trimester onwards, for abdominal size significant associations with delivery mode could be observed from the 31th/32th week of gestation onwards.

This effect is independent of other well documented risk factors sich as maternal age, body height and prepregnancy weight status. The results of the present study may indicate, that risks for operative deliveries can be predicted much earlier than assumed. Further studies are absolutely necessary to define cut offs which may enable a better planning of deliveries. Consequently, fetal growth patterns should be monitored very carefully.

Authors' contributions

SK designed the study, analyzed the data and drafted the manuscript. BH designed the study and collected the data

Conflict of interest

The authors declare that there is no conflict of interest.

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