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FETAL WEIGHT ESTIMATION USING FRACTIONAL FETAL THIGH VOLUME

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Abstract

Introduction: Three-dimensional ultrasound as a new method for fetal weight estimation makes it possible to calculate fetal weight by obtaining volumes of different parts of the fetus such as fetal thigh volume (VolTh), which is quickly measured and highly reproducible between different observers.

Aim: The aim of this study is to determine the accuracy of calculating the fetal weight based on thigh volume (VolTh) obtained by three-dimensional ultrasound in relation to the actual birth weight.

Methods: A cross-sectional study in which 120 pregnant women who gave birth were included. Each patient`s anamnesis with an emphasis on inclusion and exclusion criteria was taken. Then, using a three-dimensional ultrasound, the volume of the fetal thigh (VolTh) was recorded, and after birth the actual birth weight of the neonate was measured.

Results: 116 patients met the inclusion criteria. The simple linear regression analysis revealed a regression equation of birth weight as: *Estimated fetal weight = 24.233 x fractional volume of the thigh + 1513.8*, with a coefficient of determination R^2=0.5761. To evaluate the precision of the new linear regression formula in birthweight prediction, a comparison among the new formula and other formulas was conducted, including Lee`s formula, Schild`s formula, Srisantiroj`s formula and the new formula. The mean absolute percentage errors (MAPE) were 8.6%, 42.41%, 8.14% and 7.2%, respectively.

Conclusion: The study showed that fetal weight can be estimated using 3D ultrasound techniques including fractional volumetry of the fetal thigh.

***Key words**:* 3-dimensional ultrasound (3DUS); Birth weight (BW); Thigh volume (VolTh)

Introduction

Fetal weight estimation is one of the major tasks in modern prenatal care. Accurate assessment may be related to critical points of decision-making and proper management. To date, ultrasound has been the main diagnostic tool for fetal weight evaluation, that is mostly estimated using formulas in which standard two-dimensional biometric parameters are included, such as: biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC) and femur length (FL) [1]. The error rate in fetal weight estimation when two-dimensional ultrasound (2DUS) is being used, can reach from 6 to 11%, depending on the biometric parameters used and the formula used for fetal weight calculation [2].

Since two-dimensional fetal measurements cannot accurately estimate fetal body volume and thus accurately calculate fetal weight, it is necessary to seek a new more precise method to calculate the fetal weight. In recent years, three-dimensional ultrasound (3DUS) has emerged as a new method by which it is possible to calculate fetal weight by obtaining volumes of different parts of the fetus [3].

In the past, many researchers who were using only the limb circumference obtained by two-dimensional ultrasound to calculate the limb volume and fetal weight, obtained calculations which have resulted in unsatisfactory results [4].

The first studies in which fetal weight was calculated using volumes obtained with three-dimensional ultrasound showed more accurate results for fetal weight compared to formulas based on standard two-dimensional biometric parameters [5,6].

Thigh volume calculated using a three-dimensional ultrasound represents a new tissue parameter that exceeds the technical limitations of two-dimensional ultrasound. This parameter is easily obtained, quickly measured and highly reproducible between various observers [7]. Changes in the volume of the fetal thigh can detect subtle changes in the amount of fetal soft tissue during pregnancy. This parameter may allow earlier detection and better monitoring of fetal soft tissue abnormalities, such as fetal growth retardation (FGR) [8].

Nowadays, even greater progress has been made in calculating fetal weight based on three-dimensional ultrasound by introducing the concept of fractional fetal thigh volume, with only five intersectional planes being measured within the volume of the limb [9].

The purpose of this study was to develop a formula for fetal weight estimation based on thigh volume (VolTh) and determining the accuracy of calculating the fetal weight based on thigh volume (VolTh). This was the first time that fractional-type volume, generated from software, has been used to evaluate the improvement in predicting fetal birth weight among a Macedonian population.

Material and methods

Cross-sectional study in which 120 pregnant women were included. All of them were likely to complete birth within the next 48 hours following admission to the department of gynecology and obstetrics at 'Dr. Trifun Panovski' Clinical Hospital in Bitola.

The inclusion criteria for this study were: singleton pregnancy, alive fetus, well-defined gestational age, normal fetal anatomy during fetal screening at 18 to 22 weeks' gestation (also confirmed by postnatal clinical examination of the newborn), and delivery less than 48 hours after 3D volume recording.

Exclusion criteria were: multiple pregnancies, fetus demise, newborn with any form of structural malformation, delayed birth by more than 48 hours after 3D ultrasound examination, and uncertain gestational age.

The demographic characteristics of the mothers, including maternal age, nationality, gestational age at the time of the examination, were obtained as anamnestic data during the mothers' admission to the health facility.

All newborns were measured immediately after birth in the delivery room with the same weighing scale, with an error of ±5 g.

The acquisition and storage of ultrasound volumes were done by placing the ultrasonic probe parallel to the longitudinal section of the fetal femur. Several volumes of the fetal thigh (VolTh) were recorded using automatic acquisition. The 3D volume window was adjusted to the size of the fetal thigh and the angle of the acquisition was set to 60 to 70°.

The volume of the fetal thigh (VolTh) was shown in three orthogonal planes: axial, sagittal, and coronal (Fig.1). The markers were placed at the ends of the diaphysis. A transverse plane was then followed by a fractional lowering of the marker from one end of the bone to the other at a distance of 5.0 mm. The perimeter of the fetal thigh in the transversal plane was manually drawn at each plane (Fig.2) A three-dimensional model of thigh volume (VolTh) for each fetus was stored on the ultrasound machine.

The thigh volume was calculated later using 4D view software (GE Medical Systems) installed in the ultrasound device, using automated modules for fetal thigh volume (VolTh).

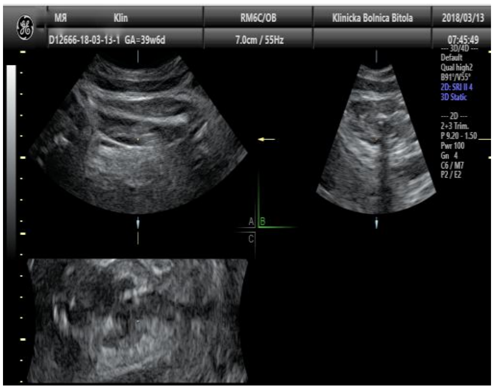


Fig.1. Fetal thigh volume (VolTh)

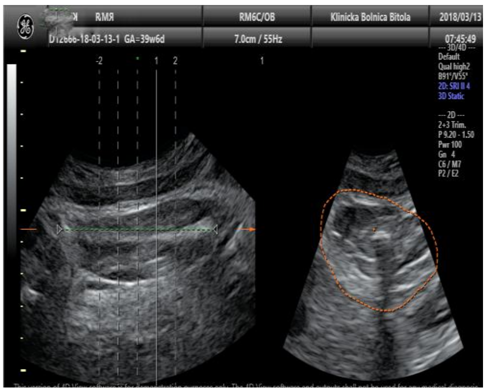


Fig.2. Perimeter drawing

All ultrasound examinations were performed transabdominally with 3D ultrasound with a Voluson E8 Expert ultrasound device with BT10 software version, with an abdominal volume matrix convex probe RM6C (2.1 to 6.1 MHz). The amount of amniotic fluid was not used as a selection criterion.

Statistical data processing was performed with SPSS for Windows ver. 17 by applying appropriate statistical methods: Descriptive statistics for describing quantitative variables, absolute and relative numbers, and categorical variables. The linear regression (correlation) method used to determine the degree or strength of the existing dependency was used to determine the relationship, the dependence between two numerical series; P <0,05 was considered to be a statistically significant difference. Data were analyzed descriptively with ± standard deviation (SD), maximum and minimum values. Pearson's correlation coefficient (R) was used to estimate the relationship between VolTh and BW. Mean percentage differences (systematic weight estimation error) and SD of the percentage differences (random weight estimation error) were used to compare the accuracy and precision of fetal weight estimation based on our local population sample.

The procedures of this study involving human participants are in compliance with the ethical standards of the Helsinki Declaration of 1964 and subsequent amendments and were approved by a decision from the Ethics Commission of the Medical Faculty in Skopje.

Results

A total of 120 patients were evaluated throughout the study period, 116 of which met the inclusion criteria. Demographic data of the patients are shown in Table 1. Data analysis indicated that the average age of the women included in the study was 30.49 ± 4.86 years, with a median of 30 years, a minimum age of 16 and a maximum of 45 years. All were Caucasian, but in terms of nationality, 88.7% women were Macedonian, 5.1% were Albanian, 2.58% were Turkish and 1.72% were Romany. The analysis showed that the average gestational fetal age in the whole sample was 39 ± 1.16 gestational weeks, with a minimum of 33.6 and a maximum of 41.4 gestational weeks.

Table 1. Patients' demographic data

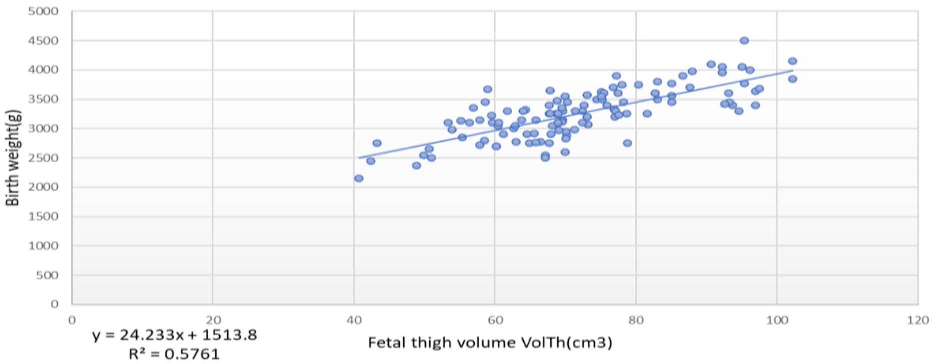
Characteristics	Mean ± SD (n = 116)	Minimum	Maximum
Age (yrs.)	30.49 ± 4.86	16	45
Weight (kg)	77±8.8	45	98
GA (weeks)	39 ± 1.16	33.6	41.4

Characteristics	Percentage	Characteristics	Percentage
Education		Nationality	
No education	1.72%	Macedonian	88.7%
Primary	12%	Albanian	5.1%
Secondary	41.3%	Turkish	2.58%
High	42.2%	Roma	1.72%
Other	0.86%	Others	1.9%
Social status		Smoking status	
Student	3%	Yes	72%
Employed	70%	No	28%
Unemployed	27%		

The average birth weight was 3260 ± 426 g, with a minimum weight of 2150 g, and a maximum of 4500 g. The mean volume of the calf was 72.072 ± 13.350 cm^3. The smallest volume of the calf was 40.654 cm^3, while the largest volume was 102.273 cm^3.

To generate a simple linear regression equation of birth weight on fractional TVol, all data of 116 fetuses were analyzed. The simple scatter plot of thigh volume against birth weight (Fig. 3) showed a positive correlation between thigh volume and birth weight, so the Pearson correlation coefficient for fractional thigh volume as the only sonographic parameter for the calculation of birth weight was r = 0.76, p < 0.001. The simple linear regression analysis revealed a regression equation of birth weight as: *Estimated fetal weight = 24.233 x fractional volume of the thigh + 1513.8*. This regression model had a coefficient of determination (R^2) =0.5761). The new formula of thigh volume by three-dimensional ultrasound had the values of error (-0.017g ± 277g), percent error (-0.76% ± 8.84%), absolute error (230.48g ± 154.6g), and absolute percent error (7.23% ± 5.15%) in predicting birth weight.

Fig 3: Fetal weight estimation based on VolTh



To evaluate the precision of the new linear regression formula in birthweight prediction, a comparison among the new formula and other formulas has been conducted, including Lee`s formula (BW = 34.649xTVol + 604.227) [5], Schild`s formula (BW=18.268*TVol+ 552.805) [10], Srisantiroj`s formula (BW = 32.568 *TVol+774.744) [11] and New formula (BW=24.233*TVol + 1513.8) (Table 2). The mean absolute percentage errors (MAPE) were 8.6%, 42.41%, 8.14% and 7.2%, respectively.

Table 2. Comparison of the mean error, mean absolute error, mean percentage error, and mean absolute percentage error and mean absolute percentage error with four different formulas (n = 116).

	LEE[5]	**Schild**[10]	**Srisantiroj**[11]	**New formula (Tvol)**
Mean Error (ME) (g)	158.85	1390.89	-3113.33	-0.02
Mean Absolute Error (MAE) (g)	283.37	1390.89	267.30	230.48
Mean Percentage Error (MPE) (%)	4.64	42.41	3.91	-0.76
Mean Absolute Perecentage Error (MAPE) (%)	8.67	42.41	8.14	7.23

Error (E) = Estimated fetal weight (EFW) - Actual birthweight (BW)
Absolute error (AE) = Absolute ((EFW - BW)
Percentage error (PE) = (EFW - BW) / BW x 100%
Absolute percentage error (APE) = Absolute ((EFW - BW)/BW x 100%
EFW = Estimated fetal weight
BW = Actual birth weigh

Discussion

Accurate determination of fetal weight is essential because of the potential complications that may arise from low and high birth weight during delivery and puerperium [12]. Calculation of fetal weight during pregnancy is an important part of prenatal and intrapartum care [13]. In late pregnancy, fetal weight calculation becomes even more important for birth planning, as perinatal complications are greater in cases where birth weight is either very low or very high [14]. During routine checkups, fetal weight calculations can influence the decisions of the mode of delivery and delivery time [15].

In everyday practice, fetal weight is calculated using formulas based on two-dimensional ultrasound with a combination of standard biometric parameters derived from three anatomical sites: fetal head, fetal abdomen, and fetal thigh. However, none of the used formulas [16] takes into consideration the amount of the soft tissue, despite the evidence that abnormal soft tissue content may be a reliable indicator of fetal growth abnormalities [17]. Such abnormalities cannot be detected if soft tissue abnormalities, which represent the earliest manifestations of abnormal growth, are not taken into consideration, unless these measurements are sensitive to the extent that they detect the subtle changes in the muscular or fatty tissue. A relatively small number of biometric parameters have been evaluated for the calculation of soft tissues such as those of fetal thigh [17] and abdomen [18].

However, the amount of soft tissue is difficult to be determined with 2D ultrasound, owing to its irregular shape. Therefore, the assumption that fetal limbs represent a proper cylinder when measuring soft tissue may lead to significant errors. Several studies have suggested measuring fetal soft tissue through the thickness or volume of the fetal thigh [19], the diameter between the two cheeks [18], the thickness of the abdominal subcutaneous tissue [20,21], and the appearance of the fetal gluteus [22]. The practical application of fetal soft tissue measurements in calculating fetal weight is limited by the unsatisfactory interobserver reproducibility of these measurements during pregnancy [22].

The first studies in which fetal weight was calculated using thigh volume (VolTh) with 3DUS reported more accurate birth weight results compared to calculations based on 2DUS formulas [10]. The review of the literature indicates that the fractional fetal thigh volume for fetal weight calculations has been used so far only in five countries in the world. Nevertheless, it is important to note in these comparisons that different models have been utilized for calculating the fetal weight. Most studies are mainly based on calculating fetal weight in the late third trimester and nearly all of them are highly reproducible in measuring the thigh volume.

In the study of Chang *et al*. [6] from 1997, the use of upper arm and thigh volume in calculating the fetal weight during the third trimester was described for the first time and the measurement procedure took around 10-15 minutes per limb. They conducted a prospective study in which they concluded that the formula for calculating fetal weight based on 3D-measured thigh volume was correct for all categories of infants, in the birth weight range from 1194 to 4425. The new formula of thigh volume by three-dimensional ultrasound had the lowest values of error (0 g), percent error (0.7%), absolute error (176.1 g), and absolute percent error (5.8%) in predicting birth weight. [23].

In 2001 Lee *et al*. [5] conducted a prospective study in which 100 fetuses were prospectively scanned with an average gestational age of 39.2 ± 1.2 weeks. The mean birth weight was 3643 ± 574 g. This study included normal-growing fetuses from the following racial groups: white (97%), black (5%) and Asian (2%). The mean volume of the thigh was 87.4 ± 19.3cm^3. For the first time fractional fetal thigh volume was used, as the only ultrasound parameter in fetal weight determination, and the mean absolute error in percentage was 5.6% ± 8.4%.

In 2009 Srisantiroj *et al*. [11] conducted a prospective, cross-sectional study of 176 Thai eligible pregnant women at the gestational age of 38.5±2.1 weeks. By using the regression model, fractional ThiV presents a superior correlation to actual BW (r = 0.965). The fitting formula was characterized by predicted fetal BW (g) = 774.744 + 32.658 x fractional ThiV (ml). The new formula of thigh volume by three-dimensional ultrasound had the values of error 2.86 + 165.30g, percent error 0.15% + 5.50%, absolute error 131.51 + 98.70 g, and absolute percent error 4.34% + 3.47% in predicting birth weight. Fetal 3D-fractional ThiV was consistent with actual BW. The conclusion of the study was that the measurement of fractional ThiV can improve the accuracy of fetal weight prediction.

In 2010 Bennini *et al*. [23] compared the accuracies of birth-weight predicting models derived from two-dimensional (2D) ultrasound parameters and from total fetal thigh volumes measured by three-dimensional (3D) ultrasound imaging; and to compare the performances of these formulae with those of previously published equations. A total of 210 patients were evaluated to create a formula-generating group (n = 150) and a prospective validation group (n = 60). The best-fit formulas for the estimation of fetal weight using 3D fetal thigh volumes were: estimated fetal weight (EFW) = 1033.286 + 12.733 × ThiM (SD of predicted values, 566.521; r = 0.919; r2 = 0.845; P < 0.001) and New 3D formula (ThiV) 0.73 ± 7.99 EFW = 1025.383 + 12.775 × ThiV (SD of predicted values, 570.6299; r = 0.926; r2 = 0.857; P < 0.001). For both the formula-generating and the prospective-validation groups, there were no significant differences between the accuracies of the new 2D and 3D models in the prediction of birth weight.

In 2011 Yang *et al*. [24] developed and validated new birth-weight prediction models in Chinese pregnant women using fractional thigh volumes of the 290 fetuses studied, 100 were used in the development of prediction models and 190 in the validation of prediction models. The prediction model M6 = 1205.016 + 24.981 × TVol using TVol, provided birth-weight estimation, with a mean percent error (MPE) of 0.38, random error of 6.08 and R^2 of 0.7174. By comparison, the Hadlock model with standard fetal biometry (BPD, head circumference, AC and FL) gave a random error of 6.41%.

A 2013 study by Lee *et al*. [25], which estimated the significance of fractional fetal thigh volume when calculating fetal weight in a population of 164 women, showed that in Model 4 (TVol) where only the thigh volume was used for calculating fetal weight, the error rate for all fetuses was 5.3 ± 11.7, whereas Model 6 (BPD, AC, TVol) turned out to be the most accurate in calculating fetal weight with an error rate of 1.9 ± 6.6%.

In the 2014 study of O Conor *et al*. [7] fetal thigh volume was not found to be a significant predictor of birth weight using univariate analysis, despite moderate-to-high correlation with other predictors (Pearson r = 0.58–0.63 with AC and EFW at all weeks; r = 0.50–0.57 with EFW centile at weeks 33 and 38). In 2017 Mohsen *et al*. [8] conducted a prospective, cross-sectional study of 150 normal pregnancies. They found out that modified Hadlock formula had higher accuracy, whereas fractional limb volume method had higher precision. Systematic errors for the modified Hadlock formula, fractional limb volume fetal weight estimation and the original mid-thigh soft tissue thickness methods were 2.3%, -4.8% and 11%, respectively, whereas the random errors were 7.7%, 6.2% and 13.8%, respectively. The percentage of cases estimated within 5%, 10% and 15% of actual fetal weight were 48%, 86% and 92%, respectively, for the modified Hadlock method, whereas for the fractional limb volume method, these were 40%, 78% and 98%, respectively. They found out that fractional limb volume method is a very promising method for fetal weight estimation, but its performance is not significantly different from the modified Hadlock method.

The results from this study indicate that the currently available 3D ultrasound techniques that enable fetal weight estimation based on volume estimation of individual fetal body parts (fetal thigh) are providing accuracy in fetal weight estimation comparable to 2D ultrasound. The results are comparable with the results from other authors that have conducted similar studies. Fractional limb volume method is a promising method with accuracy and precision approaching the 2DUS formulas, which are considered referent in everyday practice in fetal weight estimation. An imaging technique that allows measurement of the entire fetal body volume might give better results. Magnetic resonance imaging has been used for this purpose, but it is not widely available and would not be cost-effective. Further technical development of 3D ultrasound imaging, allowing volume acquisition of the whole uterus, might be another way towards improving accuracy.

In conclusion, the present prospective comparative study showed that fetal weight can be estimated using 3D ultrasound techniques including fractional volumetry of the fetal thigh. This proved true for both the recently published 3D formulae and for a new formula based on the 3D measurements of our own population. 3D ultrasound techniques require technically sophisticated and expensive ultrasound equipment, special training, and extra skills for examiners, and are time consuming. Therefore, it does not seem reasonable, at least at present, to abandon the 2D ultrasound methods in favor of 3D ultrasound imaging for FW estimation in normal pregnancies.

Study limitations: The low number of participants in study population is possibly a drawback. It may have affected the results of fractional limb volume method and the generated formula. This may have had an impact on the results of this study. Secondly, the obtained formula was not applied on a new random group to determine its accuracy. A new separate study should be undertaken to address this issue.

References

1. Jordaan HV. Estimation of fetal weight by ultrasound. J Clin Ultrasound JCU. 1983 Mar;11(2):59–66.
2. Dudley NJ. A systematic review of the ultrasound estimation of fetal weight. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2005 Jan;25(1):80–9.
3. Bernstein IM, Horbar JD, Badger GJ, Ohlsson A, Golan A. Morbidity and mortality among very-low-birth-weight neonates with intrauterine growth restriction. The Vermont Oxford Network. Am J Obstet Gynecol. 2000 Jan;182(1 Pt 1):198–206.
4. Barker DJ. The fetal and infant origins of disease. Eur J Clin Invest. 1995 Jul;25(7):457–63.

5. Lee W, Deter RL, Ebersole JD, Huang R, Blanckaert K, Romero R. Birth weight prediction by three-dimensional ultrasonography: fractional limb volume. J Ultrasound Med Off J Am Inst Ultrasound Med. 2001 Dec;20(12):1283–92.
6. Chang FM, Liang RI, Ko HC, Yao BL, Chang CH, Yu CH. Three-dimensional ultrasound-assessed fetal thigh volumetry in predicting birth weight. Obstet Gynecol. 1997 Sep;90(3):331–9.
7. O'Connor C, O'Higgins A, Doolan A, Segurado R, Stuart B, Turner MJ, *et al*. Birth weight and neonatal adiposity prediction using fractional limb volume obtained with 3D ultrasound. Fetal Diagn Ther. 2014;36(1):44–8.
8. Mohsen LA, Amin MF. 3D and 2D ultrasound-based fetal weight estimation: a single center experience. J Matern-Fetal Neonatal Med Off J Eur Assoc Perinat Med Fed Asia Ocean Perinat Soc Int Soc Perinat Obstet. 2017 Apr;30(7):818–25.
9. Simcox LE, Myers JE, Cole TJ, Johnstone ED. Fractional fetal thigh volume in the prediction of normal and abnormal fetal growth during the third trimester of pregnancy. Am J Obstet Gynecol. 2017 Oct;217(4): 453.e1-453.e12.
10. Schild RL, Fimmers R, Hansmann M. Fetal weight estimation by three-dimensional ultrasound. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2000 Oct;16(5):445–52.
11. Srisantiroj N, Chanprapaph P, Komoltri C. Fractional thigh volume by three-dimensional ultrasonography for birth weight prediction. J Med Assoc Thail Chotmaihet Thangphaet. 2009 Dec;92(12):1580–5.
12. Zylbersztejn A, Gilbert R, Hjern A, Hardelid P. How can we make international comparisons of infant mortality in high income countries based on aggregate data more relevant to policy? BMC Pregnancy Childbirth. 2017 Dec 19;17(1):430.
13. Chauhan SP, Hendrix NW, Magann EF, Morrison JC, Kenney SP, Devoe LD. Limitations of clinical and sonographic estimates of birth weight: experience with 1034 parturients. Obstet Gynecol. 1998 Jan;91(1):72–7.
14. Levine TA, Grunau RE, Segurado R, Daly S, Geary MP, Kennelly MM, *et al*. Pregnancy-specific stress, fetoplacental haemodynamics, and neonatal outcomes in women with small for gestational age pregnancies: a secondary analysis of the multicentre Prospective Observational Trial to Optimise Paediatric Health in Intrauterine Growth Restriction. BMJ Open. 2017 Jun 21;7(6): e015326.
15. Zahran M, Tohma YA, Erkaya S, Evliyaoğlu Ö, Çolak E, Çoşkun B. Analysis of the effectiveness of ultrasound and clinical examination methods in fetal weight estimation for term pregnancies. Turk J Obstet Gynecol. 2015 Dec;12(4):220–5.
16. Boutin A, Jastrow N, Roberge S, Chaillet N, Bérubé L, Brassard N, *et al*. Reliability of 3-dimensional transvaginal sonographic measurement of lower uterine segment thickness. J Ultrasound Med Off J Am Inst Ultrasound Med. 2012 Jun;31(6):933–9.
17. Deter RL, Lee W, Sangi-Haghpeykar H, Tarca AL, Yeo L, Romero R. Individualized fetal growth assessment: critical evaluation of key concepts in the specification of third trimester size trajectories. J Matern-Fetal Neonatal Med Off J Eur Assoc Perinat Med Fed Asia Ocean Perinat Soc Int Soc Perinat Obstet. 2014 Apr;27(6):543–51.
18. Bethune M, Bell R. Evaluation of the measurement of the fetal fat layer, interventricular septum and abdominal circumference percentile in the prediction of macrosomia in pregnancies affected by gestational diabetes. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2003 Dec;22(6):586–90.
19. Deter RL, Nazar R, Milner LL. Modified neonatal growth assessment score: a multivariate approach to the detection of intrauterine growth retardation in the neonate. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 1995 Dec;6(6):400–10.
20. Abramowicz JS, Sherer DM, Bar-Tov E, Woods JR. The cheek-to-cheek diameter in the ultrasonographic assessment of fetal growth. Am J Obstet Gynecol. 1991 Oct;165(4 Pt 1):846–52.
21. Galan HL, Rigano S, Radaelli T, Cetin I, Bozzo M, Chyu J, *et al*. Reduction of subcutaneous mass, but not lean mass, in normal fetuses in Denver, Colorado. Am J Obstet Gynecol. 2001 Oct;185(4):839–44.
22. Matsumoto M, Yanagihara T, Hata T. Three-dimensional qualitative sonographic evaluation of fetal soft tissue. Hum Reprod Oxf Engl. 2000 Nov;15(11):2438–42.

23. Lindell G, Marsál K. Sonographic fetal weight estimation in prolonged pregnancy: comparative study of two- and three-dimensional methods. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2009 Mar;33(3):295–300.
24. Bennini JR, Marussi EF, Barini R, Faro C, Peralta CFA. Birth-weight prediction by two- and three-dimensional ultrasound imaging. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2010 Apr;35(4):426–33.
25. Yang F, Leung K-Y, Hou Y-W, Yuan Y, Tang MH-Y. Birth-weight prediction using three-dimensional sonographic fractional thigh volume at term in a Chinese population. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2011 Oct;38(4):425–33.
26. Lee W, Deter R, Sangi-Haghpeykar H, Yeo L, Romero R. Prospective validation of fetal weight estimation using fractional limb volume. Ultrasound Obstet Gynecol Off J Int Soc Ultrasound Obstet Gynecol. 2013 Feb;41(2):198–203.