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Estimation of fetal weight using Hadlock's formulas: Is head circumference an essential parameter?

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ABSTRACT

Objectives: To test the equivalence of two fetal weight estimation formulas generated by Hadlock, a formula that includes head circumference parameter (H1), and another (H2) which excludes this parameter. A secondary aim was to identify the patients in which H2 formula is less reliable to use.

Study design: This retrospective cohort study included a total of 1220 sonographic fetal weight estimations performed within seven days of delivery and recorded at a single medical center from January 2014 to December 2016. Estimated fetal weight was calculated using H1 and H2 formulas. Their accuracies were compared using percentage error, the proportion of weight estimations falling within ±15% error interval and by Bland-Altman analysis. Multivariate regression was performed to evaluate factors affecting weight estimation by H2 formula.

Results: The mean birth weight was 3288.92 ± 641.27gr. The H2 formula presented with statistically significant higher value of systemic mean percent error comparing to H1 (3.19% vs. 1.87%, $p < 0.001$ respectively). H2 formula had a lower accuracy compared to H1 in predicting fetal weight within ±15% of birth weight (90.49% vs. 93.44%, $p < 0.01$ respectively). Using Bland-Altman analysis, the 95% limits of agreement between both formulas were (-142.03) to 231.79gr with a mean of 44.88gr. Factors found to influence significantly on H2 formula were long femur length (OR 1.144, $p < 0.0001$) and low maternal age (OR 0.947, $p < 0.01$).

Conclusions: H1formula was more accurate than H2 formula in predicting fetal weight at term. However, the accuracy difference was found to be small. Therefore, if ultrasonographic evaluation of HC is technically difficult, Hadlock formula that excludes head circumference can be used with confidence. Caution should be paid with higher values of femur length and lower maternal age.

Introduction

Birth weight is an important predictive parameter of neonatal morbidity and mortality [1]. Therefore, accurate prenatal estimation of birth weight is a key step in the management of labor and delivery. Measurements performed within seven days of delivery are assumed to be the most accurate when calculating the estimated fetal weight (EFW) and in the prediction of birth weight [2].

Several formulas (based on regression analysis) have been developed for estimating fetal weight [3–5]. These formulas include different combinations of sonographic biometric parameters. This sonographic estimation of fetal weight is then compared to the nomograms for gestational age in order to identify fetal growth abnormalities.

Typically, biometric parameters that are measured and incorporated into the formula for calculating estimated fetal weight (EFW) include a combination of biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL) [6].

There is still no consensus on which model yields the best sonographic fetal weight estimation [6,7]. However, the commonly used formulas in the USA, and in WHO reports [8] are those proposed by Hadlock and colleagues [4,9,10]. Likewise, Hadlock's

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Table 1
Clinical data of the study population.

Population (n)	1220
Gravidity (n)	3 (1–19)
Parity (n)	2 (1–14)
Maternal Age at Birth (years)	30.13 + 5.96
Gestational age at birth (days)	273.13 + 11.84
Male / Female [n (%)]	657 (53.9%) / 563 (46.1%)
Difference between US and birth (days)	2 (0–7)
Abdominal Circumference (cm)	33.83 + 3.02
Femur Length (cm)	7.25 + 0.40
Head Circumference (cm)	33.16 + 1.54
Infant Birth Weight (grams)	3288.92 + 641.27

Data is presented as median (interquartile range), mean ± SD, number (percentage).

formulas are those being used in our medical center. There are numerous Hadlock formulas which use multiple parameters in different combinations, only few of them are in clinicaluse. In this paper, we utilized the most commonly used formula which is referred to as Hadlock-1 (H1). This formula incorporates HC, AC and FL parameters for EFW calculation.

As fetal weight is largely influenced by fetal head mass, it is not surprising that the importance of HC measurement in predicting EFW has been pinpointed [11]. Nevertheless, very often, it may be impossible to accurately measure fetal HC; for instance, when the head is deeply engaged into maternal pelvis or if it is maintaining a direct occiput in either anterior or posterior position. In such cases, it is desirable to have a technique for fetal weight estimation that does not include head measurements.

Our group has noticed that in many cases, it is possible to utilize Hadlock-2 (H2) formula, which solely includes AC and FL, and disregards HC without affecting the accuracy of EFW.

Considering the observation mentioned above, we hypothesized that EFW calculated by using H2 formula is almost equivalent to that calculated by using H1 formula, in its capability of predicting birth weight.

The primary aim of our study was to assess the accuracy of Hadlock's EFW formula which excludes the HC parameter in comparison to the accuracy of the widely used Hadlock's EFW formula that includes the HC parameter.

Materials and methods

Data collection

This retrospective cohort study assessed sonographic and obstetric data of pregnancies and deliveries at Soroka Medical Center between January 2014 and December 2016. Sonographic fetal weight estimations were performed in our Ultrasound Unit by skilled and experienced physicians and sonographers. Using an Excel spreadsheet, we used sonographic fetal measurements obtained up to one week before delivery and calculated the estimated fetal weight using two different Hadlock formulas; one that included HC, AC and FL and the other that included only AC and FL (H1, H2 respectively).Data wereretrieved from a computed database. The EFW was then compared to the actual birth weight retrieved from the computerized delivery ward files.

Table 3
Summary of the proportion of predictions within the range of +15% of birth weight.

	Hadlock 1 (AC, FL, HC)	Hadlock 2 (AC, FL)	p-value
Predictions (%) within ±15% of birth weight	93.44%	90.49%	0.007

Our database was filtered according to our inclusion criteria: live-birth singleton pregnancy; fetal birth weight >500 g; gestational age at delivery> 24 weeks; ultrasound performed < 7 days prior to birth. Congenital fetal musculoskeletal or cranial malformations as well as incomplete medical records were exclusion criteria for participation in the study.

Independent variables were collected for all cases of the study: birth weight, HC, AC, FL, maternal age, maternal weight, gravidity, parity, birth week and gender of newborn.

The institutional review board approved the study that has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Statistical analysis

Data were summarized using means with standard deviation (SD), medians with interquartile range (IQR) and percentage. Fetal sonographic measurements were entered into the two Hadlock formulas to calculate the expected fetal weight. EFW calculated for each formula was compared to the actual birth weight that serves as the "gold standard" for comparison – with the relevant margin of equivalence being the EFW within +15% of the actual birth weight. Following data collection, statistical analysis was performed in 4 stages:

Stage 1

An adjustment of 26.26gr per day between last ultrasound and date of birthwas added to the predicted birth weight for each case (EFW + 26.26 * [number of days between ultrasound EFW and birth weight]), this adjustment was derived from a report of the World Health Organization [8].

In order to accurately compare the Hadlock formulas, and to properly stratify the effect of different variables on their accuracy, results were classified with comparison to the actual birth weight as over-estimation, under-estimation or within range (+15%). Next, univariate analysis was performed to compare the sub-groups for each formula.

Stage 2

The systemic mean percent error (%error) was calculated for all cases per formula using the following equation: $\%Error = \frac{(Adjusted\ EFW)-(Birth\ Weight)}{Birth\ Weight} \times 100\%$. Paired Student's *t*-test was used to assess the difference between the formulas.

Table 2
Summary of mean percent error and absolute mean percent error of each formula.

Parameter n=1220	H1 (HC, AC, FL)	H2 (AC, FL)	p-value
Adjusted mean EFW (gr)	3339.88 + 647.961	3384.76 + 669.266	<0.0001
Systemic mean percent error	1.87 + 7.94	3.19 + 8.49	<0.0001
Absolute mean percent of deviation from EFW	6.36 + 5.10	7.06 + 5.68	<0.0001

Data is presented as mean ± SD.
EFW, estimated fetal weight.

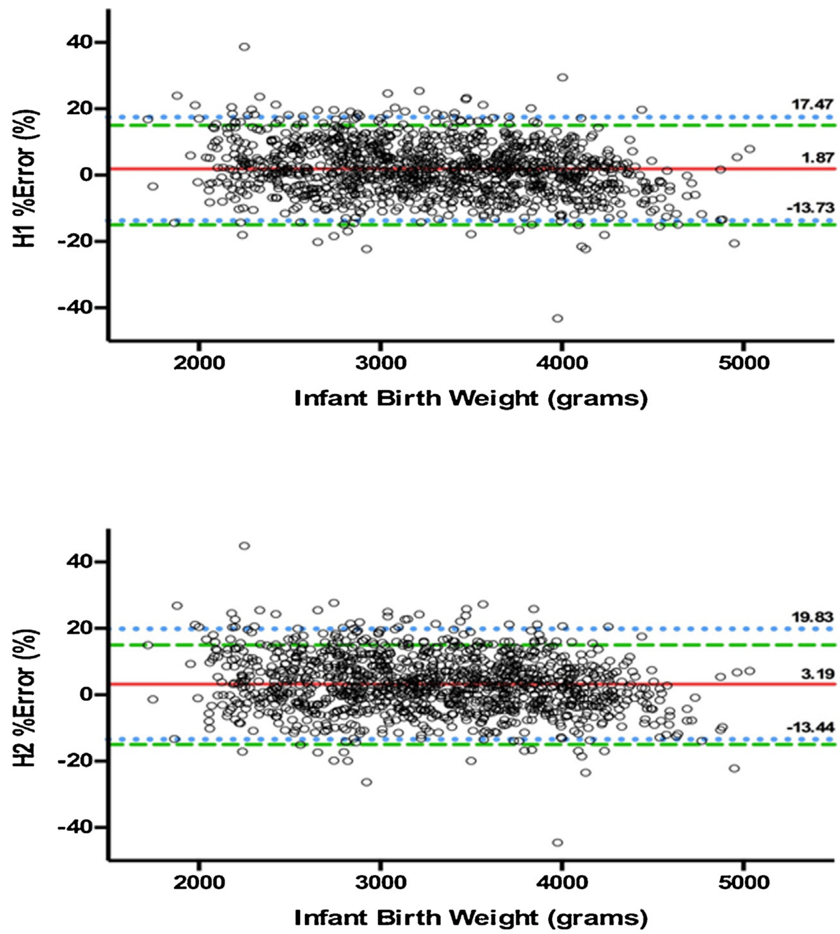

Fig. 1. Scatterplots demonstrating correlation between infant birth weight and %error of H1 (a) and H2 (b) equations.
Red line indicates mean percent error; dotted blue lines indicate 95% confidence interval; dashed green lines indicate margins of error. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Scatterplot graphs were created to demonstrate the relationship between the percent error (%Error) calculated for each Hadlock formula and the actual birth weight while showing horizontal lines for confidence interval and margin of error.

In addition, we calculated the proportion of the predictions within range for each Hadlock formula, with (H1) or without (H2) the fetal HC.

Stage 3

Two Bland-Altman plots [12] were formed to study the limits of agreement between each Hadlock formula and the gold standard of the actual birth weight. An additional Bland-Altman plot was formed by constructing limits of agreements between the two formulas.

Stage 4

Additional analyses were performed with the use of multivariable logistic regression adjusted only for the statistically significant pre-defined baseline covariates: abdominal circumference, femur length, maternal age at birth in years, difference in days between sonographic weight estimation and actual day of birth and adjusted estimated fetal weight (binned into groups of 100 g).

Due to the small number of cases with under-estimations of EFW, the multivariate analysis was performed per Hadlock formulaonly between cases with the EFW within ±15% of actual birth weight and cases where the EFW was larger than 15% ("over-estimation"), with the latter being the outcome variable. Lastly, we applied a step-forward binary logistic regression model. P-value less than0.05 was considered to be significant. The analysis was done with SPSS package 24th edition (SPSS Inc, Chicago, IL, USA).

Results

The clinical data for the study population is shown in Table 1. A number of 1220 sonographic fetal weight estimations were included in this study. The mean maternal age was 30.13 ± 5.96 years; the median gravidity was three (range, 1–19) and median parity was two (range, 1–14). The mean birth weight was 3288.92 ± 641.27 g. The mean gestational age at delivery was 273.13 ± 11.84 days.

The Hadlock formulas used in this study are described in Supplementary Table 1. In the comparison of H1 and H2 formulas, the H1 formula presented a value of systemic mean percent error of 1.87% ± 7.94%, which is lower compared to 3.19% ± 8.49% for H2 (difference of 1.32%, $p < 0.0001$, Table 2). Thisis also manifested in higher accuracy in predicting EFW with 93.44% prediction for H1 within the clinically acceptable margin of ±15% of birth weight, comparing to 90.49% for H2 ($p < 0.01$, difference of 2.95%, Table 3).

Scatter plots demonstrating the relationship between the error calculated percent for the H1 formula and H2 formula, and the actual birth weight are shown in Fig. 1a and b, respectively. The horizontal lines illustrate the 95% confidence level (±1.96 SD) and the clinically accepted margin of error (±15%), accordingly. As graphically demonstrated, most of the values of percentage error fall within the clinically accepted margin for both formulas.

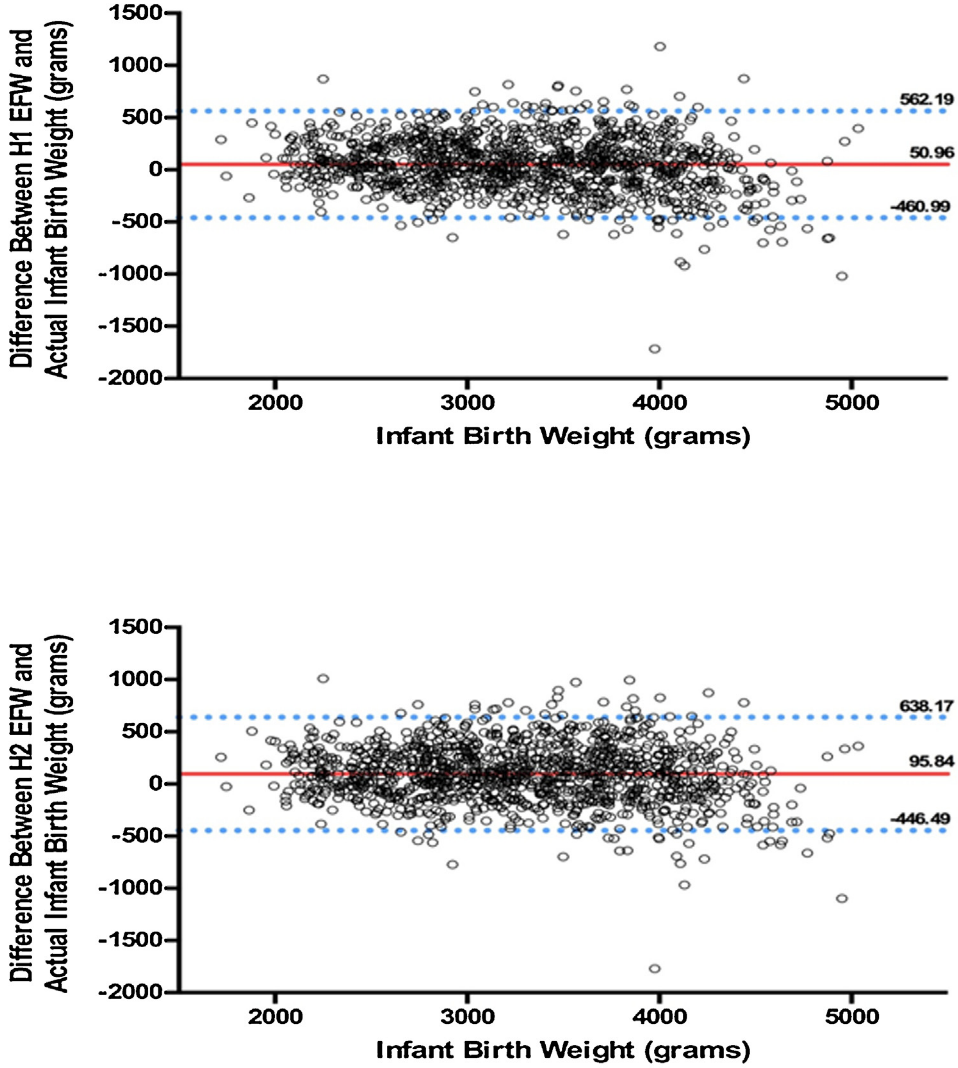

Fig. 2. Bland-Altman analysis plots comparing infant birth weight and the EFW of H1 (a) and H2 (b) equations.
Red line indicates mean of the differences between EFW of each Hadlock formula and actual birth weight (in grams); dotted blue lkines indicate limits of agreement. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

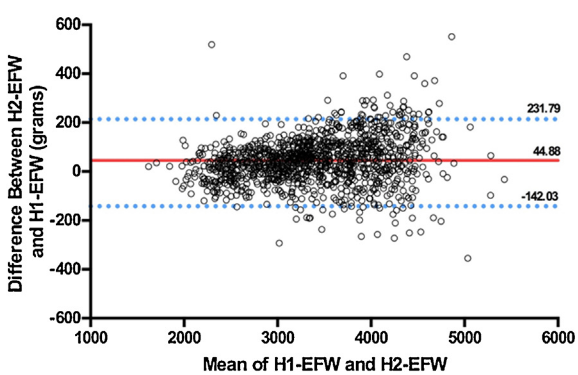

Fig. 3. Bland-Altman analysis plot comparing the two Hadlock formulas.
Red line indicates mean of the differences of EFW of the two Hadlock formulas (bias, in grams); dashed blue lines indicate limits of agreement. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the Bland-Altman analysis illustrated in Fig. 2, the limits of agreement are shown between each Hadlock formula and the actual birth weight (gold standard), while Fig. 3 shows the relationship between the two formulas. For H1 equation, a mean of 50.96 gris seen with 95% limits of agreement of (-460.99 g) to 562.91gr. For the H2 formula, a mean of 95.84 gris observed with 95% limits of agreement of (-446.49 g) to 638.17gr. Bland-Altman analysis comparing both formulas revealed 95% limits of agreement of (-142.03) to 231.79 g with a mean of 44.88 g.

In addition, the variables appeared to be statistically significant in the univariate analysis (Supplementary table 2) were pre-selected to establish a step-forward binary logistic regression model for each formula. The results of these models, summarized in Tables 4 and 5, stratify the statistically significant variables considered to be potential risk factors for overestimation of fetal weight. For the H1 formula, the only variable found to be statistically significant was femur length (OR = 1.095; 95% CI, 1.027–1.168, $p < 0.01$). For the H2 formula, the only two variables found to be significant were femur

Table 4
Multivariate analysis showing relevant variables for the H1 equation.

Potential Risk Factor	OR	CI 95%	p-value	In Equation?
Femur Length	1.095	1.027 – 1.168	0.006	Yes
Abdominal Circumference	–	–	0.361	No
Adjusted EFW (100 gr binned)	–	–	0.073	No

Table 5
Multivariate analysis showing relevant variables for the H2 equation.

Potential Risk Factor	OR	CI 95%	p-value	In Equation?
Femur Length	1.144	1.082 – 1.209	<0.001	Yes
Maternal Age at Birth	0.947	0.913 – 0.982	0.003	Yes
Abdominal Circumference	–	–	0.753	No
Days difference between US and birth	–	–	0.723	No
Adjusted EFW (100 gr binned)	–	–	0.931	No

length (OR1.144; 95% CI, 1.082–1.209, $p < 0.01$), and maternal age at birth (OR 0.947; 95% CI, 0.913 – 0.982, $p < 0.01$).

Discussion

The most commonly used parameters for the estimation of fetal weight are HC, AC and FL. In clinical practice, however, head measurements are frequently inaccurate and often difficult to measure. In our study, we focused on asking a very specific question, hoping to determine whether HC measurements are dispensable when estimating fetal weight using Hadlock's most commonly used equations [4,9].

Our study confirms previous observations [13–15] that both Hadlock formulas, including (H1) and excluding HC (H2), succeed in predicting the actual birth weight. Moreover, we found minor differences between both Hadlock formulas in predicting fetal weight, as the H1 formula demonstrates slightly higher accuracy, expressed in higher percentages of prediction within the ±15% margin (2.95% difference) as well as in lower percent error (1.32% difference). These differences are statistically significant, however being this small, its clinical relevance is questionable.

To further assess the accuracy and the relationship between the two formulas, we used a difference-based approach (Bland-Altman analysis), which is more recommended than correlation-based approaches, this is because a high correlation does not necessarily imply that there is good agreement between the two methods [12]. The first step of Bland-Altman analysis, comparing each formula with the gold standard, actually used to estimate birth weight, revealed that both formulas slightly overestimate the birth weight (more with the H2 formula). However, comparable means and limits of agreement were observed between both formulas. This outcome supports our earlier discussed results that H2 formula is no less accurate than H1. The subsequent Bland-Altman comparison between the two formulas showed minimal bias, and a narrow agreement interval, suggesting high agreement between the formulas.

When both formulas fail to predict the fetal weight within a 15% margin, they tend to overestimate the birth weight rather than to underestimate it. Further stratification analysis of both formulas indicates that the mean birth weight of the overestimation group (>15%) is lower than the means of the other groups ("underestimation" and "within range"). This observation is of concern, since it indicates that both Hadlock formulas discussed may tend to falsely predict higher weightsforsmallerfetuses. Nevertheless, Gabbay-Benziv et al [16] have previously shown that H1 would still account as the most accurate formula for small for gestational age prediction.

Most studies that compared the accuracy of existing models were limited by a small number of sonographic examinations [17–19]. Our study population is relatively large (1220 cases), however, the underestimation groups (<-15%) of the two formulas included only few cases (Supplementary Table 2); thus, one should be careful in drawing conclusions regarding these groups. An additional advantage to our study, and unlike previous studies in the field [20,21], is that our population is multiethnic, which may be of great value to offer a wider look and view.

The results from the step-forward regression model indicate that femur length is a potential risk factor for EFW overestimation for both Hadlock formulas inspected. Therefore, in such cases, one should be skeptic regarding the accuracy of any of the formulas, and probably consider using a different fetal weight estimation formula. However, in the current study, we did not explore the question of which possible formulas may be appropriate to use in higher femur length values. Moreover, we found that, specifically for H2, lower maternal age at birth is an additional overestimation risk factor. For this reason, if H2 is decided to be used for EFW calculation rather than H1, for instance in cases in which the fetal head is deeply engaged in the maternal pelvis, one should take this parameter into consideration, since lower maternal age can result in inaccurate estimate. Other variables that turned out to be of significance in previous studies, such as the gender of the newborn [22], turned out to not relevant in our current work. Our study did not include maternal BMI which had no influence on the estimation of fetal weight according to other studies [23] nor did we dedicate specific analysis for severe macrosomia, which may be essential for birth planning, as other groups have suggested [21].

Conclusions

In conclusion, according to our results, Hadlock formula that includes head circumference (H1) is more accurate than the one excluding it (H2). However, the differences between the prediction and error rates between both formulas are minor and clinically questionable. Thus we conclude that, if HC is technically difficult to obtain, then H2 can be used with confidence as an alternative to H1. Nevertheless, when using H2, extra caution should be taken in cases of higher femur length and lower maternal age.

Declaration of Competing Interest

The study received no financial support. We have full control of all primary data and agree to allow the journal to review the data if requested.

There is no commercial disclosure or other conflict of interest by any of the authors involved.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ejogrb.2019.09.024.

References

[1] Arias E, MacDorman MF, Strobino DM, Guyer B. Annual summary of vital statistics–2002. Pediatrics 2003;112:1215–30.
[2] Basha AS, Abu-Khader IB, Qutishat RM, Amarin ZO. Accuracy of sonographic fetal weight estimation within 14 days of delivery in a Jordanian population using Hadlock formula 1. Med Princ Pract 2012;21:366–9.
[3] Campbell S, Wilkin D. Ultrasonic measurement of fetal abdomen circumference in the estimation of fetal weight. Br J Obstet Gynaecol 1975;82:689–97.
[4] Hadlock FP, Harrist RB, Sharman RS, Deter RL, Park SK. Estimation of fetal weight with the use of head, body, and femur measurements–a prospective study. Am J Obstet Gynecol 1985;151:333–7.
[5] Shepard MJ, Richards VA, Berkowitz RL, Warsof SL, Hobbins JC. An evaluation of two equations for predicting fetal weight by ultrasound. Am J Obstet Gynecol 1982;142:47–54.

[6] Dudley NJ. A systematic review of the ultrasound estimation of fetal weight. Ultrasound Obstet Gynecol 2005;25:80–9.
[7] Melamed N, Yogev Y, Meizner I, Mashiach R, Bardin R, Ben-Haroush A. Sonographic fetal weight estimation: which model should be used? J Ultrasound Med 2009;28:617–29.
[8] Kiserud T, Piaggio G, Carroli G, Widmer M, Carvalho J, Neerup Jensen L, et al. The World Health Organization fetal growth charts: a multinational longitudinal study of ultrasound biometric measurements and estimated fetal weight. PLoS Med 2017;14:e1002220.
[9] Hadlock FP, Harrist RB, Fearneyhough TC, Deter RL, Park SK, Rossavik IK. Use of femur length/abdominal circumference ratio in detecting the macrosomic fetus. Radiology 1985;154:503–5.
[10] Kurmanavicius J, Burkhardt T, Wisser J, Huch R. Ultrasonographic fetal weight estimation: accuracy of formulas and accuracy of examiners by birth weight from 500 to 5000 g. J Perinat Med 2004;32:155–61.
[11] Warsof SL, Wolf P, Coulehan J, Queenan JT. Comparison of fetal weight estimation formulas with and without head measurements. Obstet Gynecol 1986;67:569–73.
[12] Giavarina D. Understanding Bland altman analysis. Biochem Med (Zagreb) 2015;25:141–51.
[13] Siemer J, Egger N, Hart N, Meurer B, Müller A, Dathe O, et al. Fetal weight estimation by ultrasound: comparison of 11 different formulae and examiners with differing skill levels. Ultraschall Med 2008;29:159–64.
[14] Hoopmann M, Abele H, Wagner N, Wallwiener D, Kagan KO. Performance of 36 different weight estimation formulae in fetuses with macrosomia. Fetal Diagn Ther 2010;27:204–13.
[15] Scott F, Beeby P, Abbott J, Edelman D, Boogert A. New formula for estimating fetal weight below 1000 g: comparison with existing formulas. J Ultrasound Med 1996;(15):669–72.
[16] Gabbay-Benziv R, Aviram A, Bardin R, Ashwal E, Melamed N, Hiersch L, et al. Prediction of small for gestational age: accuracy of different sonographic fetal weight estimation formulas. Fetal Diagn Ther 2016;40:205–13.
[17] Tongsong T, Piyamongkol W, Sreshthaputra O. Accuracy of ultrasonic fetal weight estimation: a comparison of three equations employed for estimating fetal weight. J Med Assoc Thai 1994;77:373–7.
[18] Nahum GG, Stanislaw H. Ultrasonographic prediction of term birth weight: how accurate is it? Am J Obstet Gynecol 2003;188:566–74.
[19] Ratanasiri T, Jirapornkul S, Somboonporn W, Seejorn K, Patumnakul P. Comparison of the accuracy of ultrasonic fetal weight estimation by using the various equations. J Med Assoc Thai 2002;85:962–7.
[20] Mirghani HM, Weerasinghe S, Ezimokhai M, Smith JR. Ultrasonic estimation of fetal weight at term: an evaluation of eight formulae. J Obstet Gynaecol Res 2005;31:409–13.
[21] Faschingbauer F, Voigt F, Goecke TW, Siemer J, Beckmann MW, Yazdi B, et al. Fetal weight estimation in extreme macrosomia (&/= 4,500 g): comparison of 10 formulas. Ultraschall Med 2012;33:E62–7.
[22] Melamed N, Yogev Y, Ben-Haroush A, Meizner I, Mashiach R, Glezerman M. Does use of a sex-specific model improve the accuracy of sonographic weight estimation? Ultrasound Obstet Gynecol 2012;39:549–57.
[23] Farrell T, Holmes R, Stone P. The effect of body mass index on three methods of fetal weight estimation. BJOG 2002;109:651–7.