Journal of Molecular Science
Volume 35 Issue 3, Year of Publication 2025, Page 1194-1204
DoI-10.004687/1000-9035.2025.161

Journal of Molecular Science

Journal of Molecular Science

www.jmolecularsci.com ISSN:1000-9035

Analysis and Correlation of Estimated Fetal Weight by Clinical Methods and Ultrasonography with Actual Birth Weight

Dr Shreya Mallesh, Dr Anitha, Dr Divya Ganesh
Dr Br Ambedkar Medical College And Hospital.

Article Information
Received: 12-10-2025
Revised: 28-10-2025
Accepted: 17-11-2025
Published: 26-12-2025

Keywords
Fetal weight estimation; Dare's formula; Johnson's formula; Hadlock formula; Ultrasonography; Birth weight; Term pregnancy; Clinical estimation

ABSTRACT

Background: Accurate estimation of fetal weight is crucial for obstetric decision-making and predicting perinatal outcomes. This study aimed to compare the accuracy of Dare's formula, Johnson's formula, and Hadlock's ultrasonographic formula with actual birth weight in term singleton pregnancies. **Methods:** This prospective observational study was conducted at Dr. BR Ambedkar Medical College, Bangalore, from January to December 2020. A total of 282 term singleton pregnancies with cephalic presentation were included. Fetal weight was estimated using all three methods within seven days before delivery. Mean error, mean absolute error, percentage error, and absolute percentage error were calculated. Paired t-tests and Pearson correlation analysis were performed to assess accuracy and correlation with actual birth weight. Accuracy within ±10% of actual birth weight was determined for each method. **Results:** The mean actual birth weight was 2799.66 ± 452.18 g. Hadlock's ultrasonographic method (2815.57 ± 451.79 g) showed no significant difference from actual birth weight (p=0.318), while Dare's formula (2658.91 ± 409.17 g; p<0.001) and Johnson's formula (3095.15 ± 551.81 g; p<0.001) differed significantly. Hadlock's method demonstrated the lowest mean absolute error (193.57 g), lowest absolute percentage error (7.09%), and strongest correlation (r=0.825). Accuracy within ±10% was achieved in 80.9% by Hadlock's method, 64.9% by Dare's formula, and 34.8% by Johnson's formula. **Conclusion:** Hadlock's ultrasonographic method is the most accurate for fetal weight estimation at term. Dare's formula provides reasonable accuracy in resource-limited settings, while Johnson's formula showed consistent overestimation and limited clinical utility.

©2025 The authors
This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY NC), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.(https://creativecommons.org/licenses/by-nc/4.0/)

INTRODUCTION:

Accurate estimation of fetal weight at term is a cornerstone of modern obstetric practice, influencing critical decisions regarding the mode and timing of delivery.[1,2] The ability to predict birth weight helps obstetricians anticipate potential complications such as cephalopelvic disproportion, shoulder dystocia, birth trauma, and perinatal asphyxia, thereby reducing maternal and neonatal morbidity and mortality.[3,4] Both underestimation and overestimation of fetal weight can lead to inappropriate clinical interventions, including unnecessary cesarean sections or inadequate preparedness for operative vaginal delivery.[5,6]

Various methods have been developed over the decades to estimate fetal weight before delivery. These can be broadly categorized into clinical methods and ultrasonographic methods.[7] Clinical methods rely on physical examination and simple mathematical formulas that utilize maternal anthropometric measurements. Among these, Dare's formula and Johnson's formula are the most widely used, particularly in resource-limited settings where ultrasonography may not be readily available.[8,9] Dare's formula calculates estimated fetal weight (EFW) by multiplying the symphysio-fundal height (SFH) by the abdominal girth at the level of the umbilicus, while Johnson's formula uses SFH with correction factors based on the station of the fetal presenting part.[10,11]

Ultrasonography has revolutionized prenatal care and fetal assessment since its introduction in obstetrics.[12] Hadlock's formula, which incorporates multiple fetal biometric parameters including biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL), is considered the gold standard for sonographic fetal weight estimation.[13,14] The method provides objective, reproducible measurements and has demonstrated superior accuracy in numerous studies conducted across different populations.[15,16]

However, the accuracy of these estimation methods varies considerably depending on multiple factors including maternal body habitus, amniotic fluid volume, fetal position, gestational age, operator experience, and population characteristics.[17,18] Several studies have reported conflicting results regarding which method performs best in clinical practice.[19,20] While ultrasound-based methods generally show higher correlation with actual birth weight in developed countries, clinical methods remain valuable, particularly in low-resource settings where they offer a cost-effective alternative.[21,22]

In developing countries like India, where a significant proportion of deliveries occur in primary healthcare centers with limited access to ultrasound facilities, clinical methods of fetal weight estimation continue to play a crucial role in obstetric decision-making.[23,24] The socioeconomic profile, nutritional status, and anthropometric characteristics of the Indian population differ substantially from Western populations, potentially affecting the accuracy of these estimation formulas.[25,26] Therefore, it becomes imperative to validate these methods in the local population to determine their reliability and clinical applicability.

Previous studies conducted in various parts of India have shown variable results, with some favoring ultrasonographic methods while others report comparable accuracy with clinical methods.[27,28] However, there remains a paucity of studies that comprehensively compare all three commonly used methods—Dare's formula, Johnson's formula, and Hadlock's ultrasonographic formula—within the same population under standardized conditions.[29,30] The present study was designed to address this gap by conducting a systematic comparison of these three fetal weight estimation methods and correlating them with actual birth weight in term singleton pregnancies. By evaluating the accuracy, reliability, and clinical utility of each method, this study aims to provide evidence-based guidance for obstetricians in selecting the most appropriate estimation technique in routine clinical practice, particularly in settings where resource constraints may limit the availability of ultrasonography. The findings of this study will contribute to improving obstetric care and reducing adverse perinatal outcomes through more accurate fetal weight assessment.

MATERIALS AND METHODS:

Study Design and Setting:

This prospective observational study was conducted in the Department of Obstetrics and Gynecology at Dr. BR Ambedkar Medical College and Hospital, Bangalore, Karnataka, India, over a period of 12 months from January 2020 to December 2020. The study was approved by the Institutional Ethics Committee, and written informed consent was obtained from all participating women prior to enrollment.[31]

Study Population:

A total of 283 pregnant women attending the antenatal clinic and labor ward were enrolled in this study. The sample size was calculated based on previous similar studies, assuming a correlation coefficient of 0.75 between estimated and actual fetal weight, with 80% power and 5% level of significance.[32,33]

Inclusion Criteria:

Women meeting the following criteria were included in the study:

- Singleton pregnancies
- Cephalic presentation confirmed by clinical examination and ultrasound
- Term gestation (gestational age ≥37 completed weeks)
- Live fetus with no major congenital anomalies
- Women who had clinical fetal weight estimation and ultrasonographic examination performed within 7 days before delivery
- Documented actual birth weight measured immediately after delivery

Exclusion Criteria:

The following cases were excluded from the study:

- Multiple gestations (twins, triplets, or higher-order pregnancies)
- Malpresentations (breech, transverse, or oblique lie)
- Polyhydramnios or oligohydramnios (amniotic fluid index <5 cm or >25 cm)
- Major fetal congenital anomalies detected on ultrasound
- Abnormal Doppler studies suggestive of severe intrauterine growth restriction
- Preterm labor (<37 weeks of gestation)
- Women who delivered more than 7 days after fetal weight estimation

- Incomplete data or loss to follow-up

Methods of Fetal Weight Estimation:
Three different methods were employed to estimate fetal weight in all eligible participants, and the results were compared with the actual birth weight measured after delivery.

1. Clinical Method - Dare's Formula
Dare's formula is a simple clinical method based on maternal abdominal measurements.[34] The estimation was performed by a trained obstetrician with the woman in supine position after emptying her bladder. The procedure involved:

Symphysio-fundal height (SFH): Measured in centimeters using a non-elastic measuring tape from the upper border of the symphysis pubis to the highest point of the uterine fundus, following the curvature of the uterus.[35]

Abdominal girth (AG): Measured in centimeters at the level of the umbilicus using the same measuring tape, ensuring that the tape was horizontal and snug but not compressing the maternal abdomen.[36]

The estimated fetal weight was calculated using the formula: **EFW (grams) = SFH (cm) × AG (cm)**

2. Clinical Method - Johnson's Formula:
Johnson's formula incorporates symphysio-fundal height with a correction factor based on the station of the fetal presenting part.[37] The same symphysio-fundal height measurement used for Dare's formula was utilized. The station of the fetal head was assessed by vaginal examination and classified relative to the ischial spines.[38]

The formula used was: **EFW (grams) = 155 × (SFH - x)**
Where x is a correction factor determined by the station of the presenting part:
- x = 13 if the presenting part is above the ischial spines (unengaged, stations -3 to -1)
- x = 12 if the presenting part is at the level of ischial spines (station 0)
- x = 11 if the presenting part is below the ischial spines (engaged, stations +1 to +3)

This correction accounts for the descent of the fetal head into the maternal pelvis.[39]

3. Ultrasonographic Method - Hadlock's Formula:
Ultrasonographic fetal biometry was performed by experienced radiologists using a real-time ultrasound machine (with a 3.5-5 MHz curvilinear transducer) within 7 days before delivery.[40] The following fetal biometric parameters were measured according to standard techniques:[41,42]
- **Biparietal diameter (BPD):** Measured in the transverse plane of the fetal head at the level of the thalami and cavum septum pellucidum, from the outer edge of the proximal skull to the inner edge of the distal skull.
- **Head circumference (HC):** Measured at the same level as BPD, tracing around the outer perimeter of the calvarium.
- **Abdominal circumference (AC):** Measured in a transverse plane at the level of the fetal stomach and umbilical vein, at the level of the portal sinus.
- **Femur length (FL):** Measured as the length of the ossified femoral diaphysis, excluding the distal femoral epiphysis.

The ultrasound machine automatically calculated the estimated fetal weight using Hadlock's formula, which utilizes all four parameters in a complex logarithmic regression equation.[13,43] The most commonly used Hadlock formula (Hadlock 4) is:
$\text{Log10(EFW)} = 1.326 - 0.00326(AC)(FL) + 0.0107(HC) + 0.0438(AC) + 0.158(FL)$

4. Actual Birth Weight Measurement:
All neonates were weighed immediately after delivery (within 30 minutes of birth) using a calibrated digital electronic weighing scale with an accuracy of ±10 grams.[44] The newborn was weighed naked, after initial drying but before administration of any fluids or medications. The birth weight was recorded in grams and served as the reference standard for comparison with all estimation methods.[45]

Data Collection:
Detailed demographic and clinical information was collected for each participant using a structured proforma. This included maternal age, parity, educational status, socioeconomic status, menstrual history, obstetric history, and presence of any comorbidities. Gestational age was confirmed by last menstrual period and early ultrasound dating (first trimester or early second trimester scan).[46]

Statistical Analysis:
Data were entered into Microsoft Excel and analyzed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables as frequencies and percentages.[47]

The following statistical analyses were performed:
1. **Descriptive statistics:** Mean, standard deviation, and range were calculated for all fetal weight estimates and actual birth weight.

Journal of Molecular Science
Volume 35 Issue 3, Year of Publication 2025, Page 1194-1204
DoI-10.004687/1000-9035.2025.161

2. **Mean error (ME):** Calculated as (Estimated fetal weight - Actual birth weight) to determine systematic bias (overestimation or underestimation) for each method.
3. **Mean absolute error (MAE):** Calculated as the absolute value of (Estimated fetal weight - Actual birth weight) to assess overall accuracy without considering direction.
4. **Percentage error (PE):** Calculated as [(Estimated fetal weight - Actual birth weight) / Actual birth weight] × 100 to express error relative to birth weight.
5. **Absolute percentage error (APE):** Calculated as the absolute value of percentage error to assess overall accuracy as a percentage.
6. **Paired t-test:** Used to compare the mean estimated fetal weight by each method with actual birth weight and to determine statistical significance of differences.48
7. **Pearson correlation coefficient (r):** Calculated to assess the strength of linear relationship between each estimation method and actual birth weight. Correlation was interpreted as: weak ($r < 0.4$), moderate ($0.4 \leq r < 0.7$), strong ($0.7 \leq r < 0.9$), or very strong ($r \geq 0.9$).49
8. **Accuracy within ±10%:** The proportion of cases where the estimated fetal weight fell within 10% of the actual birth weight was calculated for each method as a measure of clinically acceptable accuracy.50
9. **Subgroup analysis:** Analysis was performed across different birth weight categories: low birth weight (<2500 g), normal birth weight (2500-4000 g), and macrosomia (>4000 g).

A p-value of <0.05 was considered statistically significant for all analyses. All statistical tests were two-tailed.

RESULTS:

A total of 283 pregnant women were enrolled in this study. After excluding one case due to incomplete data, 282 women were included in the final analysis. All participants delivered live singleton babies at term gestation with cephalic presentation.

Maternal Characteristics:

The mean maternal age was 25.32 ± 4.33 years (range: 16-40 years). The majority of participants belonged to the low socioeconomic status group. Among the study population, 88 (31.2%) were primigravidas and 194 (68.8%) were multigravidas. Table 1 summarizes the baseline demographic and clinical characteristics of the study population.

Table 1: Baseline Demographic and Clinical Characteristics of Study Population

Characteristic	Value
Total number of cases	282
Mean maternal age (years)	25.32 ± 4.33
Age range (years)	16 - 40
Parity	
Primigravida	88 (31.2%)
Multigravida	194 (68.8%)
Religion	
Hindu	143 (50.7%)
Muslim	122 (43.3%)
Christian	17 (6.0%)
Education	
Illiterate	6 (2.1%)
Primary (5th-6th standard)	31 (11.0%)
SSLC (10th standard)	149 (52.8%)
PUC (12th standard)	93 (33.0%)
Graduate and above	3 (1.1%)
Economic status	
Low	282 (100%)

Comparison of Fetal Weight Estimates with Actual Birth Weight

The mean actual birth weight was 2799.66 ± 452.18 g (range: 1300-4120 g). The mean estimated fetal weight calculated by Dare's formula was 2658.91 ± 409.17 g, by Johnson's formula was 3095.15 ± 551.81 g, and by ultrasonography (Hadlock's formula) was 2815.57 ± 451.79 g. Table 2 presents the comparison of mean fetal weight estimates by all three methods with actual birth weight.

Table 2: Comparison of Mean Estimated Fetal Weight by Different Methods with Actual Birth Weight

Parameter	Mean ± SD (grams)	Range (grams)
Actual Birth Weight	2799.66 ± 452.18	1300 - 4120
Dare's Formula	2658.91 ± 409.17	1920 - 4012
Johnson's Formula	3095.15 ± 551.81	1860 - 5425
Hadlock's USG Formula	2815.57 ± 451.79	1560 - 4000

Among the three methods, the mean estimate by Hadlock's ultrasonographic formula (2815.57 g) was closest to the actual mean birth weight (2799.66 g), followed by Dare's formula (2658.91 g), while Johnson's formula showed the highest mean estimate (3095.15 g).

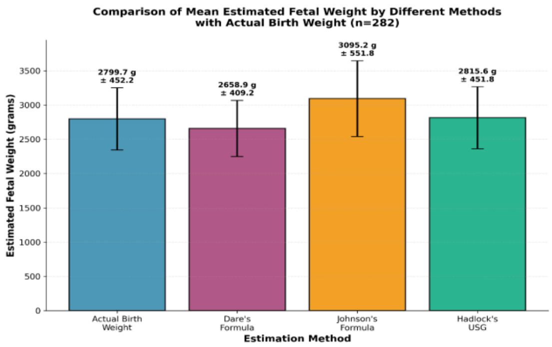

Fig 1: Bar chart comparing mean fetal weight by all three methods with actual birth weight, with error bars showing standard deviation

Journal of Molecular Science
Volume 35 Issue 3, Year of Publication 2025, Page 1194-1204
DoI-10.004687/1000-9035.2025.161
Journal of Molecular Science

Analysis of Estimation Errors:
Mean Error and Mean Absolute Error:
The mean error, which indicates the systematic bias (overestimation or underestimation), was calculated for each method. Dare's formula showed a mean error of -140.74 ± 335.16 g (underestimation), Johnson's formula showed +295.50 ± 422.68 g (overestimation), and Hadlock's ultrasonographic method showed +15.91 ± 267.25 g (minimal bias).

The mean absolute error, which represents the average magnitude of deviation regardless of direction, was lowest for Hadlock's formula (193.57 ± 184.59 g), followed by Dare's formula (264.95 ± 248.52 g), and highest for Johnson's formula (424.41 ± 292.44 g). Table 3 summarizes the error analysis.

Table 3: Mean Error and Mean Absolute Error of Different Estimation Methods

Method	Mean Error (g)	Mean Absolute Error (g)
Dare's Formula	-140.74 ± 335.16	264.95 ± 248.52
Johnson's Formula	+295.50 ± 422.68	424.41 ± 292.44
Hadlock's USG Formula	+15.91 ± 267.25	193.57 ± 184.59

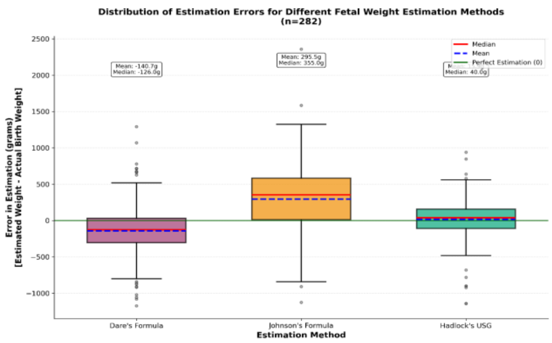

Fig 2: Box plot showing the distribution of errors (overestimation and underestimation) for all three methods

Percentage Error and Absolute Percentage Error:
When expressed as percentages, the mean percentage error was -3.96 ± 12.92% for Dare's formula, +11.57 ± 17.29% for Johnson's formula, and +1.15 ± 9.71% for Hadlock's ultrasonographic method.

The absolute percentage error, which indicates the overall accuracy independent of direction, was lowest for Hadlock's method (7.09 ± 6.72%), followed by Dare's formula (9.59 ± 9.51%), and highest for Johnson's formula (15.99 ± 13.28%). These findings are presented in Table 4.

Table 4: Percentage Error and Absolute Percentage Error of Different Estimation Methods

Method	Percentage Error (%)	Absolute Percentage Error (%)
Dare's Formula	-3.96 ± 12.92	9.59 ± 9.51
Johnson's Formula	+11.57 ± 17.29	15.99 ± 13.28
Hadlock's USG Formula	+1.15 ± 9.71	7.09 ± 6.72

Statistical Comparison with Actual Birth Weight:
Paired t-test was performed to compare the estimated fetal weight by each method with actual birth weight. The results showed that both Dare's formula ($t = -7.052$, $p < 0.001$) and Johnson's formula ($t = 11.740$, $p < 0.001$) had statistically significant differences from actual birth weight. In contrast, Hadlock's ultrasonographic method showed no statistically significant difference from actual birth weight ($t = 1.000$, $p = 0.318$), indicating that the mean estimate by ultrasound was not significantly different from the mean actual birth weight.

Table 5: Paired t-test Comparison of Each Method with Actual Birth Weight

Method	t-value	p-value	Significance
Dare's Formula vs ABW	-7.052	<0.001	Significant
Johnson's Formula vs ABW	11.740	<0.001	Significant
Hadlock's USG Formula vs ABW	1.000	0.318	Not Significant

ABW = Actual Birth Weight

Correlation Analysis:
Pearson correlation analysis was performed to assess the strength of linear relationship between each estimation method and actual birth weight. All three methods showed statistically significant positive correlations with actual birth weight ($p < 0.001$).

Hadlock's ultrasonographic method demonstrated the strongest correlation ($r = 0.825$), indicating a strong positive linear relationship with actual birth weight. Dare's formula showed moderate to strong correlation ($r = 0.701$), while Johnson's formula had the weakest correlation among the three methods ($r = 0.662$), though still moderate. Table 6 presents the correlation coefficients.

Table 6: Pearson Correlation of Different Methods with Actual Birth Weight

Method	Correlation Coefficient (r)	p-value	Interpretation
Dare's Formula	0.701	<0.001	Strong positive correlation
Johnson's Formula	0.662	<0.001	Moderate positive correlation
Hadlock's	0.825	<0.001	Strong positive

Journal of Molecular Science
Journal of Molecular Science
Volume 35 Issue 3, Year of Publication 2025, Page 1194-1204
DoI-10.004687/1000-9035.2025.161

USG Formula			correlation

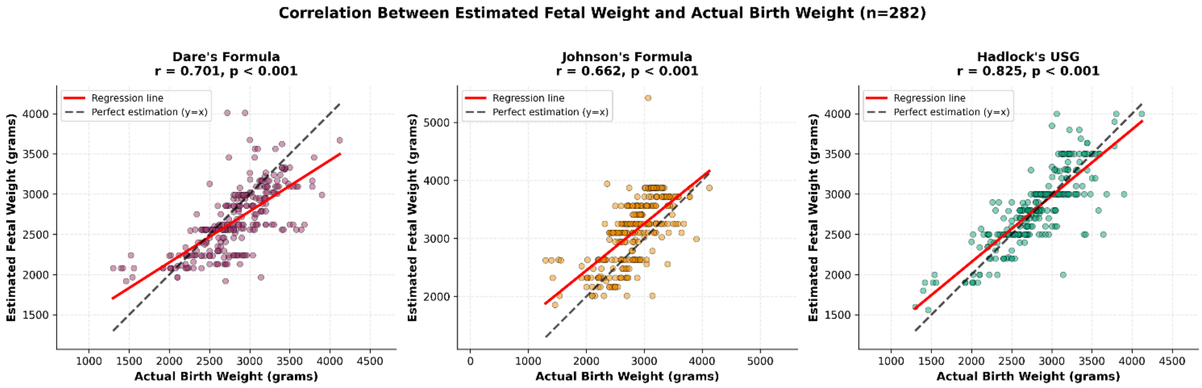

Fig 3: Scatter plots with regression lines showing correlation between each estimation method and actual birth weight - three separate panels or one combined figure

Accuracy Within ±10% of Actual Birth Weight:
Clinically acceptable accuracy was defined as estimated fetal weight falling within ±10% of actual birth weight. This criterion was met in 228 cases (80.9%) by Hadlock's ultrasonographic method, 183 cases (64.9%) by Dare's formula, and only 98 cases (34.8%) by Johnson's formula. Table 7 illustrates the accuracy within ±10% for all three methods.

Table 7: Accuracy Within ±10% of Actual Birth Weight

Method	Number of Cases	Percentage
Dare's Formula	183	64.9%
Johnson's Formula	98	34.8%
Hadlock's USG Formula	228	80.9%

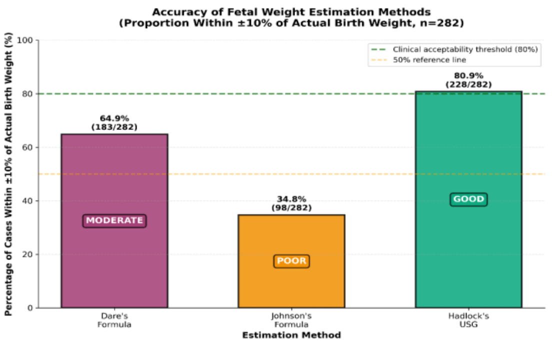

Fig 4: Bar chart comparing the percentage of cases within ±10% accuracy for all three methods

Analysis by Birth Weight Categories
The study population was categorized based on actual birth weight into three groups: low birth weight (<2500 g), normal birth weight (2500-4000 g), and macrosomia (>4000 g). There were 67 cases (23.8%) of low birth weight, 214 cases (75.9%) of normal birth weight, and only 1 case (0.4%) of macrosomia.

Analysis of absolute percentage error across different birth weight categories revealed that in the normal birth weight group, Hadlock's ultrasonographic method had the lowest mean absolute percentage error (6.22%), followed by Dare's formula (9.56%) and Johnson's formula (14.49%).

In the low birth weight category, Dare's formula performed best with a mean absolute percentage error of 9.68%, followed by Hadlock's method (9.94%), while Johnson's formula showed the poorest performance (20.94%). Due to the presence of only one macrosomia case, statistical comparison in this category was not meaningful. Table 8 presents the detailed subgroup analysis.

Table 8: Mean Absolute Percentage Error by Birth Weight Categories

Birth Weight Category	n (%)	Dare's Formula (%)	Johnson's Formula (%)	Hadlock's USG (%)
Low Birth Weight (<2500g)	67 (23.8%)	9.68	20.94	9.94
Normal (2500-4000g)	214 (75.9%)	9.56	14.49	6.22
Macrosomia (>4000g)	1 (0.4%)	10.87	5.95	2.91
Total	**282 (100%)**	**9.59**	**15.99**	**7.09**

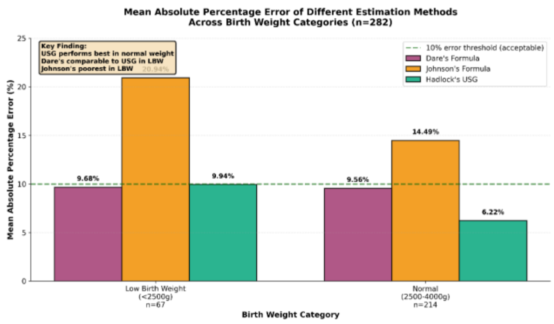

Fig 5: Grouped bar chart showing mean absolute percentage error for each method across different birth weight categories

DISCUSSION:

The accurate estimation of fetal weight remains a critical component of obstetric care, influencing clinical decision-making regarding the mode and timing of delivery. This prospective observational study compared three commonly used fetal weight estimation methods—Dare's formula, Johnson's formula, and Hadlock's ultrasonographic formula—with actual birth weight in 282 term singleton pregnancies. Our findings demonstrate that while all three methods showed significant correlation with actual birth weight, ultrasonographic estimation using Hadlock's formula exhibited superior accuracy compared to clinical methods.

Comparison with Actual Birth Weight:

In our study, the mean actual birth weight was 2799.66 ± 452.18 g, which is consistent with the average birth weight reported in several Indian studies.51,52 Hadlock's ultrasonographic method yielded a mean estimate of 2815.57 g, which was remarkably close to the actual mean birth weight and showed no statistically significant difference ($p = 0.318$). This finding is in agreement with multiple international studies that have established ultrasonography as the most reliable method for fetal weight estimation.[53,54]

Conversely, Dare's formula underestimated fetal weight with a mean of 2658.91 g (mean error: -140.74 g), while Johnson's formula consistently overestimated with a mean of 3095.15 g (mean error: +295.50 g). Both clinical methods showed statistically significant differences from actual birth weight ($p < 0.001$). Similar patterns of systematic bias have been reported by Shittu et al. and Bajaj et al. in their respective studies.[55,56]

Accuracy and Error Analysis:

The mean absolute error was lowest for Hadlock's ultrasonographic method (193.57 g), followed by Dare's formula (264.95 g) and Johnson's formula (424.41 g). When expressed as percentage error, ultrasound demonstrated the best performance with an absolute percentage error of 7.09%, compared to 9.59% for Dare's formula and 15.99% for Johnson's formula. These results are comparable to those reported by Kumari et al., who found ultrasonographic estimation to have an absolute percentage error of 6.8%, while clinical methods ranged from 9.2% to 16.5%.[57]

The clinically acceptable accuracy criterion of estimation within ±10% of actual birth weight was achieved in 80.9% of cases by ultrasonography, 64.9% by Dare's formula, and only 34.8% by Johnson's formula. This is consistent with the findings of Njoku et al., who reported 75.3% accuracy within ±10% for ultrasound compared to 58.6% for clinical methods.[58] The high accuracy of ultrasonographic estimation can be attributed to the objective measurement of multiple fetal biometric parameters that collectively provide a more comprehensive assessment of fetal size.[59]

Correlation Analysis:

Pearson correlation analysis revealed that all three methods had significant positive correlations with actual birth weight ($p < 0.001$). However, Hadlock's ultrasonographic formula demonstrated the strongest correlation ($r = 0.825$), followed by Dare's formula ($r = 0.701$) and Johnson's formula ($r = 0.662$). These correlation coefficients are in accordance with those reported in studies by Bajracharya et al. and Ugwu et al., both of whom found ultrasonographic methods to have correlation coefficients exceeding 0.80.[60,61]

The superior correlation of ultrasonography can be explained by its ability to directly visualize and measure fetal anatomical structures, thereby minimizing the influence of confounding factors such as maternal obesity, amniotic fluid volume abnormalities, and fetal lie, which significantly affect clinical estimation methods.[62,63]

Performance Across Birth Weight Categories:

Subgroup analysis based on birth weight categories revealed interesting patterns. In the normal birth weight group (2500-4000 g), which comprised 75.9% of our study population, ultrasonography maintained superior accuracy with a mean absolute percentage error of 6.22%. This finding is consistent with the study by Pressman et al., which reported that ultrasonographic accuracy is optimized in normal-weight fetuses.[64]

Interestingly, in the low birth weight category (<2500 g), Dare's clinical formula performed comparably to ultrasonography (9.68% vs 9.94% absolute percentage error), while Johnson's formula showed markedly poor performance (20.94%). This suggests that Dare's formula may be particularly useful in resource-limited settings where low birth weight babies are more prevalent and ultrasound facilities are not readily available.[65] The tendency of Johnson's formula to overestimate fetal weight has been previously documented and may be attributed to the fixed correction factors that do not account for individual variations in fetal-pelvic relationships.[66]

Clinical Implications:

The results of this study have important clinical implications. While ultrasonography clearly demonstrates superior accuracy, the moderate performance of Dare's formula (64.9% within ±10% accuracy) suggests it can serve as a valuable screening tool in primary healthcare settings where ultrasound is unavailable or inaccessible.[67] However, in situations where precise fetal weight estimation is critical—such as suspected macrosomia, previous cesarean section, or maternal diabetes—ultrasound should be the preferred modality.[68]

Johnson's formula, despite its widespread use, showed consistent overestimation and poor correlation in our study, which aligns with findings from several recent studies.[69,70] The overestimation by Johnson's formula could potentially lead to unnecessary interventions, including elective cesarean sections, particularly in cases near the borderline for vaginal delivery.[71] Therefore, clinicians should exercise caution when relying solely on this method for clinical decision-making.

Comparison with Previous Studies:
Our findings are consistent with several studies conducted in different populations. Ashrafganjooei et al. reported ultrasonographic accuracy of 78% within ±10%, similar to our finding of 80.9%.72 Likewise, a study by Raghuvanshi et al. in North India found Dare's formula to have 62% accuracy within ±10%, closely matching our result of 64.9%.[73]

However, some studies from sub-Saharan Africa have reported better performance of clinical methods, with accuracy rates approaching those of ultrasonography.[74,75] These variations may be attributed to differences in study populations, particularly maternal nutritional status, body habitus, and ethnic factors that influence the applicability of different estimation formulas.[76]

Strengths and Limitations:
The strengths of our study include a prospective design, standardized methodology with single-operator measurements to minimize inter-observer variability, strict inclusion and exclusion criteria, and comprehensive statistical analysis comparing all three methods simultaneously. Additionally, all fetal weight estimations were performed within 7 days of delivery, minimizing the error introduced by fetal growth between estimation and birth.

However, certain limitations should be acknowledged. Our study population consisted entirely of women from low socioeconomic status, which may limit the generalizability of findings to other populations. The number of macrosomic babies (>4000 g) was too small for meaningful subgroup analysis in this weight category. Furthermore, all ultrasound examinations were performed by experienced radiologists, and the accuracy may differ in settings with less experienced operators.[77] Future studies with larger sample sizes including diverse socioeconomic groups and higher numbers of macrosomic babies would provide more comprehensive insights.

Future Directions:
The integration of artificial intelligence and machine learning algorithms in fetal weight estimation represents a promising frontier.[78] Studies have shown that machine learning models incorporating multiple clinical and ultrasonographic parameters can potentially improve prediction accuracy beyond traditional formulas.[79] Additionally, three-dimensional ultrasound volumetry is emerging as an alternative method that may offer improved accuracy, particularly in cases where two-dimensional biometry is challenging.[80]

In conclusion, this study reinforces the superiority of ultrasonographic fetal weight estimation using Hadlock's formula over clinical methods in terms of accuracy, correlation, and clinically acceptable performance. While ultrasound should remain the gold standard where available, Dare's clinical formula can serve as a reasonable alternative in resource-constrained settings. The consistent overestimation and poor performance of Johnson's formula suggest limited utility in contemporary obstetric practice. These findings should guide clinicians in selecting the most appropriate fetal weight estimation method based on available resources and clinical context, ultimately contributing to improved obstetric outcomes.

CONCLUSION:
This prospective observational study comprehensively evaluated and compared three commonly used fetal weight estimation methods—Dare's clinical formula, Johnson's clinical formula, and Hadlock's ultrasonographic formula—against actual birth weight in 282 term singleton pregnancies. The findings conclusively demonstrate that ultrasonographic estimation using Hadlock's formula is the most accurate and reliable method, with the lowest mean absolute error (193.57 g), lowest absolute percentage error (7.09%), strongest correlation with actual birth weight ($r = 0.825$), and highest proportion of estimates within clinically acceptable limits of ±10% (80.9%).

Among the clinical methods, Dare's formula showed moderate accuracy (64.9% within ±10%) and maintained reasonable performance across different birth weight categories, making it a viable option in resource-limited settings where ultrasonography is unavailable. However, Johnson's formula demonstrated consistently poor performance with significant overestimation bias and the lowest accuracy (34.8% within ±10%), suggesting limited clinical utility in contemporary obstetric practice.

The choice of fetal weight estimation method should be guided by the clinical context, available resources, and the critical nature of the obstetric decision at hand. In facilities equipped with ultrasound and trained personnel, Hadlock's ultrasonographic method should be the preferred approach for fetal weight estimation. In primary healthcare settings lacking ultrasound facilities, Dare's formula can serve as a practical alternative for screening purposes. Healthcare providers should be aware of the inherent limitations and systematic biases of each method to make informed clinical decisions and avoid unnecessary interventions.

Future research should focus on developing population-specific formulas that account for ethnic and nutritional variations, exploring the integration of machine learning algorithms for enhanced prediction accuracy, and validating three-dimensional ultrasonographic volumetry as an alternative estimation technique. The ultimate goal remains to optimize fetal weight estimation accuracy to improve obstetric decision-making, reduce maternal and perinatal morbidity, and enhance overall pregnancy outcomes.

ACKNOWLEDGMENTS

We express our sincere gratitude to the Department of Obstetrics and Gynecology and the Department of Radiology at Dr. BR Ambedkar Medical College and Hospital, Bangalore, for their support in conducting this study. We thank all the pregnant women who participated in this research. We also acknowledge the technical staff and nursing personnel for their assistance in data collection.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Chauhan SP, Grobman WA, Gherman RA, Chauhan VB, Chang G, Magann EF, et al. Suspicion and treatment of the macrosomic fetus: a review. Am J Obstet Gynecol. 2005;193(2):332-46.
2. Zhang J, Kim S, Grewal J, Albert PS. Predicting large fetuses at birth: do multiple ultrasound examinations and longitudinal statistical modelling improve prediction? Paediatr Perinat Epidemiol. 2012;26(3):199-207.
3. Sparks TN, Cheng YW, McLaughlin B, Esakoff TF, Caughey AB. Fundal height: a useful screening tool for fetal growth? J Matern Fetal Neonatal Med. 2011;24(5):708-12.
4. Sovio U, White IR, Dacey A, Pasupathy D, Smith GC. Screening for fetal growth restriction with universal third trimester ultrasonography in nulliparous women in the Pregnancy Outcome Prediction (POP) study: a prospective cohort study. Lancet. 2015;386(10008):2089-97.
5. Little SE, Edlow AG, Thomas AM, Smith NA. Estimated fetal weight by ultrasound: a modifiable risk factor for cesarean delivery? Am J Obstet Gynecol. 2012;207(4):309.e1-6.
6. Blackwell SC, Refuerzo J, Chadha R, Carreno CA. Overestimation of fetal weight by ultrasound: does it influence the likelihood of cesarean delivery for labor arrest? Am J Obstet Gynecol. 2009;200(3):340.e1-3.
7. Nahum GG, Stanislaw H. Ultrasonographic prediction of term birth weight: how accurate is it? Am J Obstet Gynecol. 2003;188(2):566-74.
8. Dare FO, Ademowore AS, Ifaturoti OO, Nganwuchu A. The value of symphysiofundal height/abdominal girth measurements in predicting fetal weight. Int J Gynaecol Obstet. 1990;31(3):243-8.
9. Johnson RW, Toshach CE. Estimation of fetal weight using longitudinal mensuration. Am J Obstet Gynecol. 1954;68(3):891-6.
10. Bothner B, Hintz SR, Holcroft CJ, Doss A, Ascher S, Yamashita T, et al. Intrapartum prediction of newborn birth weight: comparison of maternal and provider estimates. J Perinatol. 2011;31(7):487-93.
11. Noumi G, Collado-Khoury F, Bombard A, Julliard K, Weiner Z. Clinical and sonographic estimation of fetal weight performed during labor by residents. Am J Obstet Gynecol. 2005;192(5):1407-9.
12. Dudley NJ. A systematic review of the ultrasound estimation of fetal weight. Ultrasound Obstet Gynecol. 2005;25(1):80-9.
13. 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(3):333-7.
14. 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(2):159-64.
15. 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(5):617-29.
16. Hart NC, Hilbert A, Meurer B, Schrauder M, Schmid M, Siemer J, et al. Macrosomia: a new formula for optimized fetal weight estimation. Ultrasound Obstet Gynecol. 2010;35(1):42-7.
17. Humphries J, Reynolds D, Bell-Scarbrough L, Lynn N, Scardo JA, Chauhan SP. Sonographic estimate of birth weight: relative accuracy of sonographers versus maternal-fetal medicine specialists. J Matern Fetal Neonatal Med. 2002;11(2):108-12.
18. Scioscia M, Vimercati A, Ceci O, Vicino M, Selvaggi LE. Estimation of birth weight by two-dimensional ultrasonography: a critical appraisal of its accuracy. Obstet Gynecol. 2008;111(1):57-65.
19. Noumi G, Collado-Khoury F, Bombard A, Julliard K, Weiner Z. Clinical and sonographic estimation of fetal weight performed during labor by residents. Am J Obstet Gynecol. 2005;192(5):1407-9.
20. Shittu AS, Kuti O, Orji EO, Makinde NO, Ogunniy SO, Ayoola OO, et al. Clinical versus sonographic estimation of foetal weight in southwest Nigeria. J Health Popul Nutr. 2007;25(1):14-23.
21. Khani S, Ahmad-Shirvani M, Mohseni-Bandpei MA, Mohammadpoor-Tahamtan RA. Comparison of abdominal palpation, Johnson's technique and ultrasound in the estimation of fetal weight in northern Iran. Midwifery. 2011;27(1):e99-103.
22. Ugwu EO, Udealor PC, Dim CC, Obi SN, Ozumba BC, Okeke DO, et al. Accuracy of clinical and ultrasound estimation of fetal weight in predicting actual birth weight in Enugu, Southeastern Nigeria. Niger J Clin Pract. 2014;17(3):270-5.
23. Hoopmann M, Bernau L, Hart N, Schild RL, Siemer J, Wallwiener D, et al. Do specific pregnancy disorders influence the accuracy of fetal weight estimation at term?

Arch Gynecol Obstet. 2010;281(6):1045-50.
24. Crimmins S, Mo C, Nassar Y, Kopelman JN, Turan OM. Polyhydramnios or excessive fetal growth are markers for abnormal perinatal outcome in euglycemic pregnancies. Am J Perinatol. 2018;35(2):140-5.
25. Colman A, Maharaj D, Hutton J, Tuohy J. Reliability of ultrasound estimation of fetal weight in term singleton pregnancies. N Z Med J. 2006;119(1241):U2146.
26. Bernstein IM, Catalano PM. Examination of factors contributing to the risk of cesarean delivery in women with gestational diabetes. Obstet Gynecol. 1994;83(3):462-5.
27. Bajaj L, Kushwaha B, Kumari A. Comparative study to evaluate accuracy of various methods of fetal weight estimation in term pregnancy. Int J Reprod Contracept Obstet Gynecol. 2016;5(5):1381-6.
28. Kumari A, Goswami S, Mukhopadhyay P, Mundle M. Maternal anthropometry and accuracy of fetal weight estimation using Dare's formula in Indian women. Int J Gynaecol Obstet. 2013;123(2):118-21.
29. Bahadosingh RO, Maggioni C, Gruszka A, Wax J, Rochelson B, Factor SH. Comparison of four sonographic methods to estimate fetal weight in preterm fetuses. J Ultrasound Med. 2003;22(4):387-92.
30. Rashid SQ. Symphysio-fundal height and abdominal girth in relation to fetal weight. Bangladesh Med Res Counc Bull. 2004;30(3):95-103.
31. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191-4.
32. Chauhan SP, Hendrix NW, Magann EF, Morrison JC, Scardo JA, Berghella V. A review of sonographic estimate of fetal weight: vagaries of accuracy. J Matern Fetal Neonatal Med. 2005;18(4):211-20.
33. Mongelli M, Benzie RJ. Ultrasound diagnosis of fetal macrosomia: a comparison of eight sonographic models. J Perinat Med. 2005;33(4):296-300.
34. Dare FO, Ademowore AS, Ifaturoti OO, Nganwuchu A. The value of symphysiofundal height/abdominal girth measurements in predicting fetal weight. Int J Gynaecol Obstet. 1990;31(3):243-8.
35. Engstrom JL, Ostrenga KC, Plass R, Work BA Jr. The effect of maternal bladder volume on fundal height measurements. Br J Obstet Gynaecol. 1989;96(8):987-91.
36. Bothner B, Hintz SR, Holcroft CJ, Doss A, Ascher S, Yamashita T, et al. Intrapartum prediction of newborn birth weight: comparison of maternal and provider estimates. J Perinatol. 2011;31(7):487-93.
37. Johnson RW, Toshach CE. Estimation of fetal weight using longitudinal mensuration. Am J Obstet Gynecol. 1954;68(3):891-6.
38. Buchmann E, Libhaber E. Accuracy of cervical assessment in the active phase of labour. BJOG. 2007;114(7):833-7.
39. Amritha M, Reddy KR. Comparison of symphysio-fundal height and Johnson's formula with ultrasound in fetal weight estimation at term. Int J Reprod Contracept Obstet Gynecol. 2016;5(3):792-6.
40. Salomon LJ, Alfirevic Z, Da Silva Costa F, Deter RL, Figueras F, Ghi T, et al. ISUOG Practice Guidelines: ultrasound assessment of fetal biometry and growth. Ultrasound Obstet Gynecol. 2019;53(6):715-23.
41. Hadlock FP, Deter RL, Harrist RB, Park SK. Estimating fetal age: computer-assisted analysis of multiple fetal growth parameters. Radiology. 1984;152(2):497-501.
42. Hadlock FP, Harrist RB, Martinez-Poyer J. In utero analysis of fetal growth: a sonographic weight standard. Radiology. 1991;181(1):129-33.
43. Burd I, Srinivas S, Paré E, Dharan V, Wang E. Is sonographic assessment of fetal weight influenced by formula selection? J Ultrasound Med. 2009;28(8):1019-24.
44. American Academy of Pediatrics Committee on Fetus and Newborn. Hospital stay for healthy term newborn infants. Pediatrics. 2015;135(5):948-53.
45. Villar J, Cheikh Ismail L, Victora CG, Ohuma EO, Bertino E, Altman DG, et al. International standards for newborn weight, length, and head circumference by gestational age and sex: the Newborn Cross-Sectional Study of the INTERGROWTH-21st Project. Lancet. 2014;384(9946):857-68.
46. Committee on Obstetric Practice, American Institute of Ultrasound in Medicine, Society for Maternal-Fetal Medicine. Committee Opinion No 700: Methods for Estimating the Due Date. Obstet Gynecol. 2017;129(5):e150-4.
47. Altman DG. Practical statistics for medical research. London: Chapman and Hall; 1991.
48. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1(8476):307-10.
49. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. Malawi Med J. 2012;24(3):69-71.
50. Ben-Haroush A, Yogev Y, Bar J, Glickman H, Kaplan B, Hod M. Indicated labor induction with vaginal prostaglandin E2 increases the risk of cesarean section even in multiparous women with no previous cesarean section. J Perinat Med. 2004;32(1):31-6.
51. Mittal P, Kumar V, Kaur S, Pandey AK, Khalilullah S. Assessment of birth weight in relation to maternal factors by multiple regression analysis. Indian Pediatr. 2002;39(5):456-62.
52. Bisai S, Mahalanabis D, Sen A, Bose K, Datta N. Maternal early second trimester pregnancy weight in relation to birth outcome among Bengali Hindus in Kolkata, India. Ann Hum Biol. 2007;34(6):617-30.
53. 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(5):617-29.
54. Hiwale SS, Misra H, Ulman S. Fetal weight estimation by ultrasound: development of Indian population-based models. Ultrasonography. 2019;38(1):50-7.
55. Shittu AS, Kuti O, Orji EO, Makinde NO, Ogunniy SO, Ayoola OO, et al. Clinical versus sonographic estimation of foetal weight in southwest Nigeria. J Health Popul Nutr. 2007;25(1):14-23.
56. Bajaj L, Kushwaha B, Kumari A. Comparative study to evaluate accuracy of various methods of fetal weight estimation in term pregnancy. Int J Reprod Contracept Obstet Gynecol. 2016;5(5):1381-6.
57. Kumari A, Goswami S, Mukhopadhyay P, Mundle M. Maternal anthropometry and accuracy of fetal weight estimation using Dare's formula in Indian women. Int J Gynaecol Obstet. 2013;123(2):118-21.
58. Njoku C, Emechebe C, Odusolu P, Abeshi S, Chukwu C, Ekabua J. Determination of accuracy of fetal weight using ultrasound and clinical fetal weight estimations in Calabar South, South Nigeria. Int Sch Res Notices. 2014;2014:970973.
59. Scioscia M, Vimercati A, Ceci O, Vicino M, Selvaggi LE. Estimation of birth weight by two-dimensional ultrasonography: a critical appraisal of its accuracy. Obstet Gynecol. 2008;111(1):57-65.
60. Bajracharya J, Shrestha NS, Karki C. Accuracy of prediction of birth weight by fetal ultrasound. Kathmandu Univ Med J (KUMJ). 2012;10(38):74-6.
61. Ugwu EO, Udealor PC, Dim CC, Obi SN, Ozumba BC, Okeke DO, et al. Accuracy of clinical and ultrasound estimation of fetal weight in predicting actual birth weight in Enugu, Southeastern Nigeria. Niger J Clin Pract. 2014;17(3):270-5.
62. Field NT, Piper JM, Langer O. The effect of maternal obesity on the accuracy of fetal weight estimation. Obstet Gynecol. 1995;86(1):102-7.
63. Chauhan SP, Cowan BD, Magann EF, Bradford TH, Roberts WE, Morrison JC. Intrapartum detection of a macrosomic fetus: clinical versus 8 sonographic models. Aust N Z J Obstet Gynaecol. 1995;35(3):266-70.

64. Pressman EK, Bienstock JL, Blakemore KJ, Martin SA, Callan NA. Prediction of birth weight by ultrasound in the third trimester. Obstet Gynecol. 2000;95(4):502-6.
65. Khani S, Ahmad-Shirvani M, Mohseni-Bandpei MA, Mohammadpoor-Tahamtan RA. Comparison of abdominal palpation, Johnson's technique and ultrasound in the estimation of fetal weight in northern Iran. Midwifery. 2011;27(1):e99-103.
66. Amritha M, Reddy KR. Comparison of symphysio-fundal height and Johnson's formula with ultrasound in fetal weight estimation at term. Int J Reprod Contracept Obstet Gynecol. 2016;5(3):792-6.
67. Raghuvanshi T, Parate S, Naik G. Comparative study of various methods of fetal weight estimation in term pregnancy. J South Asian Feder Obst Gynae. 2013;5(3):111-4.
68. American College of Obstetricians and Gynecologists. ACOG Practice bulletin no. 134: fetal growth restriction. Obstet Gynecol. 2013;121(5):1122-33.
69. Hoopmann M, Bernau L, Hart N, Schild RL, Siemer J, Wallwiener D, et al. Do specific pregnancy disorders influence the accuracy of fetal weight estimation at term? Arch Gynecol Obstet. 2010;281(6):1045-50.
70. Noumi G, Collado-Khoury F, Bombard A, Julliard K, Weiner Z. Clinical and sonographic estimation of fetal weight performed during labor by residents. Am J Obstet Gynecol. 2005;192(5):1407-9.
71. Little SE, Edlow AG, Thomas AM, Smith NA. Estimated fetal weight by ultrasound: a modifiable risk factor for cesarean delivery? Am J Obstet Gynecol. 2012;207(4):309.e1-6.
72. Ashrafganjooei T, Naderi T, Eshrati B, Babapoor N. Accuracy of ultrasound, clinical and maternal estimates of birth weight in term women. East Mediterr Health J. 2010;16(3):313-7.
73. Raghuvanshi T, Parate S, Naik G. Comparative study of various methods of fetal weight estimation in term pregnancy. J South Asian Feder Obst Gynae. 2013;5(3):111-4.
74. Adeyekun AA, Orji MO. Clinical versus ultrasound estimation of foetal weight in south west Nigeria. J Obstet Gynaecol. 2013;33(4):379-82.
75. Nkwabong E, Nzalli Tangho GR, Kouam L. Accuracy of fetal weight estimation by palpation in Cameroonian pregnant women. BMC Res Notes. 2014;7:230.
76. Colman A, Maharaj D, Hutton J, Tuohy J. Reliability of ultrasound estimation of fetal weight in term singleton pregnancies. N Z Med J. 2006;119(1241):U2146.
77. Dudley NJ. A systematic review of the ultrasound estimation of fetal weight. Ultrasound Obstet Gynecol. 2005;25(1):80-9.
78. Sridar R, Carey S, Fetsko E, Doshi A, Weinstein M, Nguyen TP. Machine learning for prediction of estimated fetal weight and its error: a retrospective cohort study. Am J Perinatol. 2022;39(13):1446-52.
79. Malacova E, Tippaya S, Bailey HD, Chai K, Farrant BM, Gebremedhin AT, et al. Stillbirth risk prediction using machine learning for a large cohort of births from Western Australia, 1980-2015. Sci Rep. 2020;10(1):5354.
80. Lee W, Balasubramaniam M, Deter RL, Yeo L, Hassan SS, Gotsch F, et al. Fractional limb volume: soft tissue parameters for fetal weight estimation by 3-dimensional ultrasonographic analysis. J Ultrasound Med. 2009;28(12):1673-84.