Accuracy of Fetal Thigh Circumference and Fractional thigh Volume in prediction of Fetal Birth Weight

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Abstract

Background: Accurately estimating fetal weight facilitates optimal care planning. Traditionally, formulas using biometric parameters like the biparietal diameter (BPD) and femur length (FL) guided assessments. More recently, ultrasound measurements of the fetal thigh circumference and fractional thigh volume emerged as promising alternative predictors.

Aim: To evaluate fetal thigh circumference & fractional thigh volume's accuracy in predicting birth weight.

Methods: We recruited 60 women in their third trimester with singleton pregnancies, excluding cases with anomalies or gestational age discrepancies. Standardized ultrasound biometry between 37-40 weeks measured parameters including BPD, abdominal circumference (AC), head circumference (HC), FL, thigh circumference (TC) & thigh volume (TVol). Estimates utilized Hadlock's, Vintzileos', Lee formulas. Actual weights were recorded post-delivery.

Results: The average age of participants was 29.38 ± 7.56 years. Gestational age varied among 37& 40.29 weeks. Actual birth weight mean was 3552.60 ± 689.87 grams. Estimated weights: Hadlock's - 3366.38 ± 590.82 grams, $p<0.001$; Vintzileos' - 3299.60 ± 630.95 grams, $p=0.003$; Lee 1 formula - 3693.07 ± 778.83 grams, $p<0.001$; Lee 2 - 3596.52 ± 754.27 grams, $p=0.012$. No significant variance among estimated & actual TC (pgreater than0.05). Strong positive correlations between actual weight and all estimates ($p<0.001$), highest for Lee 2 ($r=0.985$) and Lee 1 formula ($r=0.984$). Multiple regression identified Lee 1 and Lee 2 formula as significant predictors ($p=0.040$, 0.002). ROC analysis found optimal sensitivity/specificity for TVol (100/95.8%), Hadlock's (100/93.7%), Lee 1 formula (100/95.8%), Lee 2 (100/95.8%) but reduced for Vintzileos' (75/87.5%).

Conclusion: Our study revealed that Lee 2 formula proved most clinically reliable. TC and TVol also strongly correlated with actual weight, indicating reliability. TVol exhibited high diagnostic value.

Keywords: fetal weight estimation, thigh circumference, fractional thigh volume, gestational age, predictive accuracy.

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Introduction

Accurate predicting the fetus birth weight is vital for the early identification of potential complications & the facilitation of appropriate interventions. Various methods exist for estimating fetus birth weight, with notable techniques including the measurement of fetus thigh circumference and fractional thigh volume [1].

Fetal thigh circumference, which involves the ultrasonic measurement of the thickness of the fetus thigh at a specific gestational age, has been proposed as a reliable indicator of fetus growth and subsequent birth weight. This method employs ultrasound technology to determine the diameter of the fetus thigh, subsequently utilizing these measurements to estimate the fetus weight [2].

Similarly, fractional thigh volume offers another non-invasive approach for estimating fetus birth weight. This technique also relies on ultrasound to evaluate the volume of the fetus thigh, which is then used to predict fetus weight. An advantage of this method is its capacity for repeated assessments over time, allowing for continuous monitoring of fetus growth [3].

Both methods have been explored as potential predictors of fetus birth weight. Nevertheless, the accuracy of fetus thigh circumference and fractional thigh volume can vary significantly across different studies and populations [4]. Factors such as gestational age notably influence their reliability. Research indicates that these methods tend to be more accurate later in pregnancy when the fetus is more fully developed [5].

Despite potential challenges, fetus thigh circumference and fractional thigh volume remain valuable tools for estimating fetus birth weight in low-risk pregnancies. It is crucial, however, to recognize their limitations and to integrate them with other diagnostic approaches like fetus biometry to enhance the accuracy of birth weight estimations [6].

While promising, fetus thigh circumference and fractional thigh volume require further investigation to fully ascertain their utility and constraints. It is important to account for variables such as gestational age and the presence of fetus anomalies when employing these methods to predict fetus birth weight [7].

This research aims to evaluate fetus thigh circumference accuracy & fractional thigh volume as predictors of fetus birth weight, with a focus on understanding the influences of gestational age and fetus development patterns on these predictive tools.

Patients and methods

Study Design & Setting

This cross-sectional research was performed among January 2023 & October 2023 at Menoufia University Hospital and Shebeen El-Kom Teaching Hospital.

Participants

We recruited 60 pregnant women from the outpatient obstetrics & gynecology clinics of the 2 hospitals. Participants were included if they were in the third trimester of pregnancy with a single, viable fetus. We excluded women with multiple gestations, pregnancies complicated by major congenital anomalies, or a gestational age discrepancy exceeding four weeks as determined by their last menstrual period relative to ultrasound findings.

Ethical Considerations

Prior to information gathering, ethical approval was obtained from the Institutional Review Board of Menoufia University, Faculty of Medicine. informed consent was secured from each participant, emphasizing the voluntary nature of their involvement & the confidentiality of their data through anonymization and secure handling.

Data Collection

Data collection began with comprehensive history taking, covering demographic details, personal and family medical history, and detailed obstetric and menstrual histories. This was followed by a thorough physical examination which included assessment of vital signs and visible health indicators (pallor, cyanosis, jaundice, lymph node enlargement).

Ultrasound Imaging Protocol

Fetus biometry was performed using a standardized ultrasound protocol with a 2-D transabdominal approach using GE LOGIQ P5, United States ultrasound machine with a 3.5 MHz abdominal probe between thirty-seven & forty weeks of pregnancy. Measurements included BPD, HC, AC, FL, TC & TVol.

Estimation of Fetal Weight

Fetus weight estimations were derived using these formulas:

- Hadlock's formula, which doesn't utilize TC as a parameter. The formula is as follows:
- Log (Expected fetus weight) = 1.487- 0.003343 × AC × FL + 0.001837 × BPD × BPD + 0.0458 × AC + 0.158 × FL [8].
- Vintzileos' formula, which uses the fetus thigh circumference as a parameter. The formula is as follows:
- Log (Birth weight) = 1.897 + 0.015 × AC + 0.057 × BPD + 0.054 × FL + 0.011 × TC [9].
- Lee formulas which used only the (Tvol):

- Lee 1: EFW = e^(4.708 + 0.7596 × ln(TVol)) [10].

- Lee 2: ln weight = − 0.8297 + 4.0344 (ln BPD) − 0.7820 (ln BPD)2 +0.7853 (ln AC) + 0.0528 (ln TVol)2 [11].

Follow-up and Measurement Validation

Participants were monitored through to delivery. For those not delivering within a week post the last scan, repeat measurements were taken. Newborns were weighed within half an hour of birth, using a calibrated neonatal scale, and thigh circumferences were measured manually to validate ultrasound estimates.

Statistical Analysis

Data handling and analysis were conducted utilizing SPSS version 26.0 & Microsoft Excel 2016. Quantitative information were explored for normality & analyzed accordingly using mean ± SD for parametric and median with interquartile ranges for non-parametric distributions. The inferential statistical methods included: Independent t-tests or Mann-Whitney U tests to compare two independent samples, paired t-tests for comparisons within the same group and pearson correlation analysis for assessing relationships between continuous variables. ROC curve analysis to determine the diagnostic accuracy of ultrasound estimates against actual neonatal weights. Significance thresholds were set at less than 0.05 for significant outcomes.

Results

The research was carried out on 60 pregnant women with single viable fetus. The age of studied women varied among 18 & 40 years with mean ±SD was 29.38± 7.56 years. The gestational age ranged from 37 to 40.29 weeks with mean ±SD was 38.58± 1.09 weeks. The mean BMI in studied cases was 26.32±2.99 Kg/m2. More than half women (61.7%) were multipara and more than half of them (61.7%) were from rural areas (Table 1).

The mean biparietal diameter (BPD) was 10.77±11.00 mm, mean head circumference was 33.03 ±1.97 mm, mean abdominal circumference (AC) was 34.10±2.40 mm, mean estimated thigh circumference was 16.17±1.66 mm while mean femur length (FL) was 7.20±0.36 mm. Regarding actual thigh circumference, it had a mean of 16.27 ±1.69 mm.

There is a significant variance among real birth weight & estimated fetus weight by Hadlock's method (Pless than 0.001) with mean difference of 186.22 grams. Also, there is a significant variance among real birth weight & estimated fetus weight by

Vintzileos' method (P=0.003) with mean difference of 253 grams. In addition, there is a significant variance among real birth weight & estimated fetus weight by Lee 1 formula (P<0.001) with mean difference of 140.47 grams. In addition, there is a significant variance among real birth weight & estimated fetus weight by Lee 2 method (P=0.012) with mean difference of 43.92 grams (Table 2).

The there is no statistically significant variance among estimated thigh circumference by ultrasound & actual thigh circumference of the studied cases (P >0.05).

There was a significant positive association among real birth weight with estimated fetus weight by Hadlock's method (r=0.967, p less than 0.001), estimated fetus weight by Vintzileos' method (r=0.934, p<0.001), estimated fetus weight by Lee 1 formula (r=0.984, p less than 0.001), estimated fetus weight by Lee 2method (r=0.985, p<0.001), and Tvol (r=0.979, p less than 0.001). Also, there was a significant positive association among real birth weight with head circumference (r=0.936, p less than 0.001), estimated TC (r=0.830, p less than 0.001), femur length (r=0.819, p less than 0.001), & femur length (r=0.819, p less than 0.001) (Table 3).

A multiple regression was run to predict factors predicting fetus birth weight. This resulted in a significant model, (p less than 0.001, R2 = 0.990). The above-mentioned predictors were examined further and indicated that fetus weight estimated by Lee 2method (p= 0.040) and fetus weight by Lee 1 formula (p= 0.002) were significant predictors (Table 4).

ROC examination was conducted to detect the diagnostic value of fetus thigh circumference, fractional thigh volume and estimated fetus weight by different formulas in prediction of fetus birth weight. Actual TC, Tvol, EFW by Hadlock's method and FW by Lee 1 formula had the highest sensitivity. While Tvol, and FW by Lee 1 formula had the highest specificity. We reported that, the sensitivity of test using estimated TC was 91.7%, the specificity was 81.2%, with AUC was 0.867. However, when we use Actual TC predict the fetus weight, we reported that, the sensitivity of the test was 100%, the specificity of 81.2% with AUC was 0.941. Tvol predict the fetus weight with sensitivity of the test was 100%, the specificity of 95.8% with AUC was 0.987. Detection of birth weight by US using Hadlock's Formula (g), we reported that, the sensitivity of test was 100%, the specificity was 93.7%, with AUC was 0.984. Though, when we use Vintzileos's Formula (g) to predict the fetus weight we reported that, the sensitivity of the test was 75%, the specificity of 87.5% with AUC was 0.814. EFW by Lee 1 formula predict the fetus weight with sensitivity of the test was 100%, the specificity of 95.8% with AUC was 0.987. EFW by Lee 2 Formula predict the fetus weight with sensitivity of the test was 100%, the specificity of 95.8% with AUC was 0.986 (Table 5).

Discussion

Estimates of fetus weight (EFWs) in late pregnancy are critical for obstetric decision-making. While fundal height and gestational age provide a crude estimation, ultrasound biometry offers superior accuracy. Commonly, EFW at 30 weeks predicts term weight using HC, AC, & FL [12].

Fetal TC was recently added as an additional biometric parameter for sonography. In addition to estimating the weight of the fetus at birth, TC is also capable of detecting changes in soft tissue masses. The inclusion of fetal TC along with other sonographic parameters has been shown to provide a more accurate estimation of fetal weight [13].

The main purpose of this research was to determine the accuracy of fetus TC & fractional TVol in predicting fetus birth weight.

In our research, we observed that the ages of the women we studied varied among 18 & 40 years, with an average age of 29.38 +7.56 years. The gestational ages of these women ranged between 37 and 40.29 weeks, with an average of 38.58 +1.09 weeks. A significant proportion, 61.7%, were multiparous, and the same percentage originated from rural areas.

Our findings align with those reported by Ali et al. [14], who investigated the precision of prenatal weight predictions based on fetal TC in a cohort of 123 pregnant women with live singleton term babies. Their study noted that the participants' ages varied among 17 & 39 years, with an average age of 26.68 years and an SD of 5.24 years. They reported gestational ages between 38 and 41 weeks, with an average of 38.78 weeks and an SD of 0.85 weeks, and found that 64.2% of the women were multiparous.

In this study, we recorded an actual mean birth weight of 3552.60 +689.87 grams. This served as the primary benchmark for evaluating the accuracy of various fetus weight estimation methods. Hadlock's method provided a slightly lower average estimate of 3366.38 +590.82 grams, indicating a tendency for conservative estimations. The Vintzileos' method estimated even lower, with a mean of 3299.60 +630.95 grams, further underestimating the actual weight. Conversely, the Lee 1 formula yielded a higher mean estimate of 3693.07 +778.83 grams, suggesting a potential overestimation. The Lee 2 method, however, presented a closer approximation to the real birth weight at an average estimate of 3596.52 +754.27 grams, demonstrating its improved accuracy. The fractional thigh volume (TVol), a separate metric, had a mean value of 102.4 +28.34, highlighting the variety of available metrics for fetal weight estimation.

Our findings are supported by Tahira et al. [7], who associated fetus TC at 36-40 weeks with birth weight, reporting an actual mean weight of 3342.4 +423.74 grams, with Hadlock's and Vintzileos' methods providing estimates of 3319.9 +354.52 grams and 3450.4 +89.68 grams, respectively.

Consistency with our results was also found in the study by Mohamed et al. [15], which reported an actual mean weight of 3204.31 +205.275 grams, with the Hadlock's, Vintzileos', and Lee 1 methods yielding estimates of 3466.35 +210.784 grams, 3244.15 +210.625 grams, and 3333.90 +476.43 grams, respectively. Their reported TVol mean was identical to ours at 102.4 +28.34.

Similarly, Park et al. [16] and Sanyal et al. [9], provided comparative findings with actual mean weights of 3025 +519 grams and 2736.79 +520.43 grams, respectively. These studies explored the efficacy of Hadlock's and Vintzileos' methods alongside TVol, with Park et al. reporting a TVol mean of 122.9 +35.6 and Sanyal et al. showcasing the predictive capabilities of both formulas in assessing fetus weight closely to real birth weight.

Furthermore, Simcox et al. [17], aimed to establish normal values for 3D fractional thigh volume in detecting fetal growth restriction during the third trimester. They found a TVol mean of 90.3, with a range from 59.3 to 121.3, underscoring the potential of 3D measurements in enhancing fetal weight estimation accuracy.

In this study, we discovered no statistically significant variance among the assessed thigh circumference measured by ultrasound & the real TC of the participants (P greater than 0.05). This finding indicates a high degree of accuracy in ultrasound measurements for estimating fetal TC.

Supporting our findings, Mohamed et al. [15], observed a similar lack of statistical significance between assessed TC by ultrasound & real TC, with a P-value of 0.0602. This parallels our results, suggesting consistency in the precision of ultrasound estimations across different cohorts.

Ali et al. [14], also found no statistically significant discrepancy between estimated and actual TC (P = 0.06), echoing the consistency of ultrasound measurement accuracy highlighted in our study and others.

Our analysis revealed statistically significant differences between actual birth weights and estimates from Hadlock's, Vintzileos', Lee 1's and Lee 2's methods. Specifically, Hadlock's underestimated by an average of 186 grams, exhibiting conservative predictions. Vintzileos' showed greater underestimation at 253 grams on average. Conversely, Lee 1's and Lee 2's estimates were closer at average discrepancies of 140 and 44 grams respectively, with Lee 1's potential for overestimation.

Support for our findings comes from Ait-Allah et al. [18], who observed statistically significant differences among the real birth weights & those assessed by Hadlock's method (P less than 0.001) and by Vintzileos' method (P<0.001), resonating with our observations of these methods' tendencies for underestimation.

Similar concordance with our outcomes was documented by Sanyal et al. [9], who detect significant differences among actual birth weights & the estimates by Hadlock's method (P<0.001) and Vintzileos' method (P<0.001), further validating the underestimation trends of these models.

Moreover, findings from Mohamed et al. [15], align with ours, highlighting significant discrepancies between actual birth weights and the estimates provided by both Hadlock's (P<0.001) and Vintzileos' (P<0.001) methods.

We observed strong positive correlations between actual weights and all method estimates. Lee 2 formula emerged most precise at r=0.985, closely followed by Lee 1's at r=0.984 and TVol at r=0.979. While Hadlock's and Vintzileos' correlations were slightly lower, they remained significantly reliable.

Supporting our findings, Mohamed et al. [15], compared the accuracy of seven sonographic formulae for estimating fetus weight at term, finding significant positive correlations among real birth weight & the Vintzileos and Hadlock IV formulae, emphasizing their relevance in achieving accurate birth weight estimates.

Additionally, Hassanein et al. [19], found a significant positive association among real birth weight & EFW estimated by Hadlock's method (p<0.001), corroborating the method's reliability and consistency in clinical practice.

Performance analyses revealed TVol's promising metrics of 100% sensitivity, 81-96% specificity and 0.987 AUC, highlighting effectiveness. Hadlock's achieved comparable results. Vintzileos' showed reduced reliability. Both the Lee 1 and Lee 2 Formula stood out for their accuracy, each achieving a sensitivity of 100%, a specificity of 95.8%, and AUCs of 0.987 and 0.986, respectively, highlighting their precision in fetal weight estimation.

Our findings align with those of Hassanein et al. [19], who reported a specificity of 88.1%& a sensitivity of 82.8% for the Hadlock formula, with an AUC of 87.1%, reflecting its substantial accuracy in fetal weight estimation compared to actual weights.

Consistently, Mlodawski et al. [20], compared the Lee 1 formula against the Hadlock I formula, observing that the Lee 1 formula exhibited a sensitivity of 85% and a specificity of 88%, with an AUC indicative of high efficacy in fetal weight prediction prior to delivery in term pregnancies.

Kang et al. [21], explored the efficiency of a model using three-dimensional thigh volume ultrasound to predict fetus weight, reporting an AUC of 0.923 for Tvol. The sensitivity and specificity of Tvol were 81.5% and 87.4%, respectively, validating the model's predictive value.

This study, has several limitations that merit consideration. Firstly, the small sample size. Secondly, the cross-sectional nature of the study restricts the ability to assess changes over time in the predictive accuracy of the methods tested. Finally, while the study explores several methods for estimating fetal weight, including the use of thigh circumference and fractional thigh volume, it does not consider potential inter-observer variability in these measurements, which could affect their reliability and validity.

Conclusion

Our study revealed that Lee 2 method was the closest method to actual weights, proving most reliable clinically. Significantly, thigh circumference and fractional thigh volume when added to 2d parametrs strongly correlated to actual weight, indicating reliability. Fractional thigh volume especially exhibited impressive diagnostic value with high sensitivity and specificity for our objectives.

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Table 1: Demographic and women characteristics.

Parameters		Studied women (N=60)
Maternal age (years)	**Mean± SD**	29.38± 7.56
	Median	30.0
	Range	18.0- 40.0
Gestational age (weeks)	**Mean± SD**	38.58± 1.09
	Median	38.5
	Range	37.0- 40.29
BMI (Kg/m^2)	**Mean± SD**	26.32±2.99
	Median	26.56
	Range	20.7 - 33.33
Parity	**Multipara**	37 (61.7%)
	Nullipara	23 (38.3%)
Residence	**Rural**	37 (61.7%)
	Urban	23 (38.3%)

SD: standard deviation,

Table 2: Comparison between actual birth weight and estimated fetal weight by different Formula.

	Studied women (N=60)					Difference	P-value
	Mean	±SD	Median	Range			
Actual birth weight (gm)	3552.60	±689.87	3567.00	2300.0	4900.0	186.22	**<0.001 (HS)**
EFW by Hadlock's method(gm)	3366.38	±590.82	3364.45	2325.0	4687.0		
Actual birth weight (grams)	3552.60	±689.87	3567.0	2300.0	4900.0	253.0	**0.003 (HS)**
EFW by Vintzileos' method(gm)	3299.60	±630.95	3310.0	2400.0	6862.0		
Actual birth weight (grams)	3552.60	±689.87	3567.0	2300.0	4900.0	140.47	**<0.001 (HS)**
EFW by Lee 1 formula (grams)	3693.07	±778.83	3820.0	2293.0	5054.0		
Actual birth weight (grams)	3552.60	±689.87	3567.0	2300.0	4900.0	43.92	**0.012 (S)**
EFW by Lee 2 method(gm)	3596.52	±754.27	3717.92	2285.48	5086.96		

P value >0.05: Not significant (NS), P value <0.05 is statistically significant (S), p<0.01 is highly significant (HS). SD: standard deviation, TC: thigh circumference

Table 3: Correlations between actual birth weight with estimated fetal weight by different Formula.

	Actual birth weight	
	r	p- value
EFW by Hadlock's method (gm)	0.967	**<0.001**
EFW by Lee 2 method (gm)	0.985	**<0.001**
EFW by Vintzileos' method (gm)	0.649	**<0.001**
EFW by Lee 1 formula (gm)	0.984	**<0.001**
Tvol	0.979	**<0.001**
Biparietal diameter (cm)	0.883	**0.659**
Head circumference (cm)	0.936	**<0.001**
Abdominal circumference (cm)	0.962	**<0.001**
Estimated TC (mm)	0.830	**<0.001**
Femur length (cm)	0.819	**<0.001**
Actual TC (mm)	0.800	**<0.001**

p≤0.05 is significant; p≤0.01 is high significant, r: Spearman correlation coefficient
EFW: Estimated fetal weight; Tvol: Fractional thigh volume, TC: thigh circumference

Table 4: Multiple linear regression analysis for factors predicting fetal birth weight

	Unstandardized Coefficients		Standardized Coefficients Beta	t	p- value
	B	Standard error			
Maternal age (years)	-2.155	1.964	-0.024	-1.097	0.278
Gestational age (weeks)	0.907	21.420	0.001	0.042	0.966
Biparietal diameter (mm)	-0.061	1.641	-0.001	-0.037	0.970
Head circumference (mm)	28.454	29.348	0.081	0.970	0.337
Abdominal circumference (mm)	-71.642	73.452	-0.249	-0.975	0.334
Estimated TC (mm)	5.612	18.227	0.013	0.308	0.760
Femur length (mm)	-622.31	348.21	-0.321	-1.787	0.080
EFW by Hadlock's method (gm)	1.798	0.962	1.540	1.870	0.068
EFWby Lee 2 method (gm)	0.285	0.135	0.244	2.108	**0.040**
EFW by Vintzileos' method (gm)	-0.031	0.030	-0.028	-1.028	0.309
Tvol	32.572	22.502	1.338	1.448	0.154
FW by Lee 1 formula (gm)	0.646	0.201	0.729	3.219	**0.002**

EFW: Estimated fetal weight; Tvol: Fractional thigh volume, TC: thigh circumference

Table 5: Accuracy of fetal thigh circumference, fractional thigh volume and estimated fetal weight by different formulas in prediction of fetal birth weight.

	Best cut off	Sensi-tivity	Speci-ficity	PPV	NPV	AUC	Accu-racy	P-val-ue
Estimated TC (mm)	15	91.7%	81.2%	83%	90.7%	0.867	87%	**<0.001**
Actual TC (mm)	15.6	100%	81.2%	84.2%	100%	0.941	94%	**<0.001**
Tvol	75.4	100%	95.8%	96%	100%	0.987	98.5%	**<0.001**
EFW by Hadlock's method (gm)	2876.8	100%	93.7%	94%	100%	0.984	98%	**<0.001**
EFW by Lee 2 method (gm)	2858	100%	95.8%	96%	100%	0.986	98.5%	**<0.001**
EFW by Vintzileos' method (gm)	2880	75%	87.5%	85.7%	77.8%	0.814	81%	**<0.001**
FW by Lee 1 formula (gm)	2970	100%	95.8%	96%	100%	0987	99.5%	**<0.001**

AUC: Area Under a Curve, p value: Probability value, NPV: Negative predictive value, PPV: Positive predictive value, EFW: Estimated fetal weight; Tvol: Fractional thigh volume

*: Statistically significant at $p \leq 0.05$