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Original Research Article

Sonographic Assessment of the Reliability of Two and Three Dimensional Measurements of Foetal Thigh Volume for Weight Prediction: A Single Centre Study

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Abstract: ***Background***: Accurately estimated foetal weight (EFW) is critical for obstetric management, yet conventional two-dimensional biometric foetal formulas often exhibit significant error margins due to their failure to account for foetal soft tissues. This study evaluated the reliability of 2-dimensional and 3-dimensional foetal thigh volume measurements as predictors of actual birth weight (ABW) within a Nigerian population. ***Materials and Methods***: This cross-sectional study was conducted among 150 apparently healthy pregnant women (36–40 weeks gestation) at a diagnostic facility in Onitsha, Anambra State. Two-dimensional biometry was performed using the Hadlock IV formula, while three-dimensional thigh volumes were examined using a Mindray (EA6132B) volumetric transducer and analyzed offline via MicroDicom software. Statistical analysis was performed using Pearson's correlation, linear regression, and Bland-Altman agreement analysis via IBM SPSS version 21.0. ***Results***: The mean ABW was 3.76 ± 0.34 kg, while that of 2-D EFW was 3.63±0.36 kg. A significant positive correlation ($p<0.001$) was found for both 2-D ($r=0.504$) ($p = < 0.001$) and 3-D ($r = 0.589$) ($p = <0.001$) thigh volumes against the actual birth weight measured at birth. The Bland-Altman analysis revealed a systematic mean bias of −0.12 kg, confirming that conventional 2-D biometry consistently underestimates birth weight in the study population. High predictive power was observed in the derived 3-D regression model ($R^2 = 0.977$). A novel prediction regression equation (3D ThV=94.947+0.276×2D ThV) was developed to estimate three-dimensional volumes from two-dimensional parameters. ***Conclusion***: Three-dimensional foetal thigh volume is a more reliable predictor of birth weight than two-dimensional measurements, as it more accurately reflects subcutaneous tissue mass. The localized regression models developed in this study provides improved weight prediction and obstetric outcomes in resource-limited settings.

Keywords: Birthweight, Foetus, Ultrasound.

INTRODUCTION

The assessment of foetal growth and development is a cornerstone of modern obstetric care and among the various metrics used to monitor intrauterine well-being, foetal weight estimation stands out as a critical indicator of neonatal outcome. In clinical practice, estimated foetal weight (EFW) serves as a primary tool for decision-making regarding the timing and mode of delivery, particularly in high-risk pregnancies involving preterm labour or suspected growth abnormalities [1].

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The clinical implications of inaccurate foetal weight estimation are profound. Low birth weight, often resulting from intrauterine growth restriction (IUGR), is not only a leading cause of infant mortality but is also linked to the Barker Hypothesis, which suggests an increased predisposition to adult-onset hypertension, type 2 diabetes, and cardiovascular disease [2]. Conversely, foetal macrosomia presents immediate mechanical risks during labor, including shoulder dystocia, brachial plexus injuries, and bone fractures [3]. For the mother, delivering a high-birth-weight-infant increases the risk of emergency cesarean sections, third-degree perineal tears, and postpartum hemorrhage [4].

For over three decades, two-dimensional (2-D) ultrasound has been the gold standard for EFW. Most practitioners rely on the "multi-parameter method," which combines measurements of the foetal head (BPD, HC), abdomen (AC), and femur (FL). However, a significant limitation of these 2-D models is their reliance on linear and circumferential measurements of skeletal and abdominal structures. These parameters often fail to account for the soft tissue component; the subcutaneous fat and muscle mass; which constitutes a large portion of foetal weight in the third trimester [5]. Consequently, 2-D formulas frequently exhibit a central tendency bias like; overestimating the weight of small fetuses and underestimating the weight of large ones, with error margins often exceeding 15% [6].

The emergence of three-dimensional (3-D) ultrasound technology offers a solution to these inaccuracies. Unlike 2-dimensional imaging, which assumes a symmetric shape for foetal body parts, 3-dimensional ultrasound allows for true volumetric assessment (VOCAL-Virtual Organ Computer-aided Analysis). By capturing the volume of the foetal thigh, which serves as a sensitive reservoir for soft tissue and fat deposition, clinicians can potentially achieve a more representative measure of the fetus's nutritional status[7]. Research has shown that fractional limb volumes are more sensitive than abdominal circumference in detecting late-onset growth restriction [8].

Despite these advancements, the application of 3-dimensional ultrasound in sub-Saharan Africa, particularly in Nigeria, remains limited by the high cost of equipment and a lack of standardized local nomograms. Foetal proportions vary significantly across different ethnic and racial groups; hence, using Western derived formulas on a Nigerian population may lead to systematic errors [9]. Therefore, establishing the reliability of both 2-dimensional and 3-dimensional thigh measurements within the local context of Anambra State is essential for improving regional neonatal outcomes. This study evaluated the reliability of 3-dimensional foetal thigh volume measurements by correlating them with conventional 2-dimensional methods and actual birth weight.

MATERIALS AND METHODS

Research Design

A prospective cross-sectional research design was adopted to evaluate the reliability of 2-D and 3-D ultrasound measurements in predicting foetal weight. This approach was selected because it allows for the real-time observation of foetal parameters in the late third trimester, followed by immediate comparison with post-delivery birth weights, thereby ensuring high data integrity.

Location of the Study

The research was conducted at Prestige Diagnostica, a prominent private diagnostic facility situated at No. 27 Enugu Road, Onitsha, Anambra State. This location was strategically chosen because Onitsha serves as a major commercial and population hub, providing a diverse and high-volume patient demographic. Furthermore, the facility is equipped with high-end volumetric ultrasound hardware (Mindray EA6132B).

Sample Size Determination and Sampling Technique

The sample size for this investigation was determined using the Cochran [10], formula for populations of unknown or infinite size. This statistical approach ensures that the study maintains sufficient power to detect significant correlations between the biometric variables. The formula is expressed as:

$n=Z^2p(1-p)/m^2$

Where n represents the desired sample size, Z is the Z-score for the 95% confidence interval (1.96), p is the estimated proportion of the population (0.5 for maximum variability), and m is the margin of error (0.1). Following the calculation, a minimum sample size of 96 was identified; however, the study ultimately recruited 150 participants to enhance the statistical robustness of the derived regression models and to account for potential attrition during the post-delivery follow-up phase. A convenience sampling technique was employed to recruit participants who met the specific clinical criteria during the study period.

Ethical Consideration

Ethical approval with reference number: NAUTH/CS/66/Vol.16/VER.3/61/2023/103 was obtained by the Human Research Ethics Committee of Nnamdi Azikiwe University, Faculty of Health Sciences and Technology. Prior to participation, each subject received a comprehensive briefing regarding the study's objectives and the non-invasive nature of the ultrasound procedures. Verbal informed consent was secured from all participants, who were explicitly informed of their right to withdraw from the study at any stage without any clinical or personal prejudice.

Subject Selection: Inclusion Criteria

Participants were recruited from pregnant women attending routine obstetric scans. To ensure the reliability of the predictive models, the following inclusion criteria were applied:

1. Gestational Age: 36–40 weeks (third trimester) was chosen because this specific window has been found to be the most sensitive predictor of neonatal adiposity and actual birth weight [11]. This period is also optimal for foetal weight prediction and allows for immediate post-delivery correlation [7].
2. Pregnancy Type: Only singleton pregnancies were included to avoid the biometry ambiguities associated with multiple gestations or twin-to-twin transfusion syndrome [12].
3. Health: Only foetuses with no observable structural abnormalities were included to maintain measurement uniformity [13].
4. Follow-up: Participants must be reachable via phone post-delivery to provide the actual birth weight.

Exclusion Criteria

1. Multiple pregnancies (twins, triplets): Foetuses with congenital anomalies or musculoskeletal deformities.
2. Maternal conditions that severely limited acoustic windows (e.g., extreme abdominal scarring).

Instrumentation and Procedures

The primary diagnostic tool used was the Mindray (EA6132B) ultrasound system, equipped with a 3.5 MHz curvilinear probe for 2-D biometry and a specialized volumetric transducer for 3-D data acquisition.

Two-Dimensional Biometry (Multi-parameter Method)

With the patient in a supine position, standard foetal biometrics were captured at established anatomical landmarks. This included the Biparietal Diameter (BPD) and Head Circumference (HC) at the level of the cavum septum pellucidum, and the Abdominal Circumference (AC) at the transverse plane of the stomach bubble and umbilical vein junction. The Femur Length (FL) was measured along the long axis of the osseous diaphysis. The system automatically calculated the estimated foetal Weight (EFW) using the Hadlock IV formula.

Volumetric Thigh Assessment (2 and 3 Dimensions)

For the 2-dimensional multi-planar volume, the length, width, and height of the thigh were measured to estimate volume based on linear dimensions. For the 3-dimensional assessment, a volumetric sweep was performed once the full contour of the femur was visualized. These data sets were analyzed offline using MicroDicom (Version 0.1.5 Beta). A semi-automated VOCAL method was employed, utilizing the ellipsoid formula:

$V=4/3\pi\ x\ (a\ x\ b\ x\ c)$

Where a, b, and c represent the radii of the prolate shaped 3-D reconstructed foetal thigh. This method was chosen for its balance of precision and reproducibility in a clinical setting.

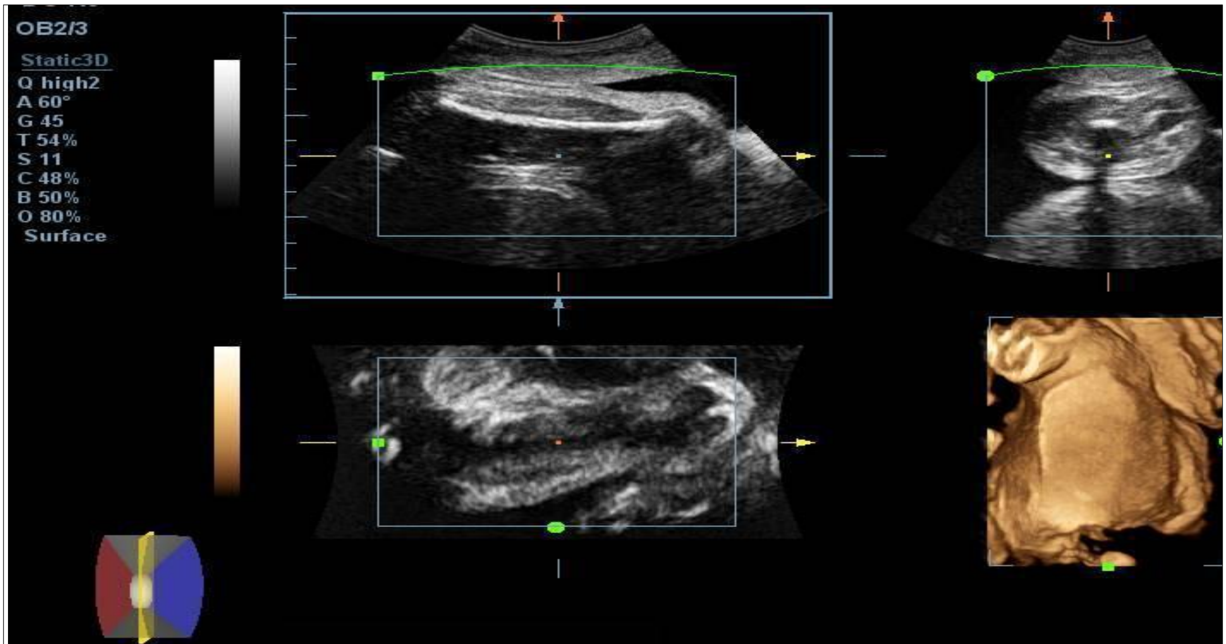

Plate 1: Pictorial representation of the reconstructed three–dimensional image of foetal thigh volume at 36weeks GA

Data Analysis

The data collected in this study were analyzed using IBM Statistical package for Social Sciences (SPSS) Version 21.0. Descriptive and inferential statistics were used in data analysis. Descriptive statistics such as mean, range, and standard deviation were used to summarize the demographic and biometric characteristics of the study population. The inferential statistical analysis was done in line with the specific objectives of the study as follows:

i. Correlation of 2-D and 3-D measurements with Birth Weight: To determine the relationship between 2-D thigh measurements, 3-D thigh volumes and the actual birth weight, Pearson's product moment correlation coefficient(r) was used.
ii. Comparison of 2-D multi-parameter accuracy: To evaluate the accuracy of the conventional Hadlock iv method against the actual birth weight, a Bland Altman agreement analysis was performed. This was used to identify any systemic bias (underestimation or overestimation) and to establish the limits of agreement between estimated and actual birth weights.
iii. Development of prediction models: To develop the novel prediction models and the regression equation for birth weight based on 3-D thigh volume, simple linear regression analysis was utilized. This allowed for the derivation of the coefficient of determination (R^2) to assess the predictive power of the new models. Furthermore, a regression equation was derived to predict 3-D thigh volumes and 2-D multi-planar measurements to address the clinical gap in clinical settings lacking 3-D hardware.

The level of statistical significance was set at p-value < 0.05 and reliability decisions were categorized into <0.5 as poor reliability, 0.5-0.75 as moderate, 0.75-0.9 as good and > 0.9 as excellent (Koo and Li, 2016).

RESULTS

The mean gestational age of the participants was 38 weeks and 5 days (38.46±1.12 weeks). As shown in Table 1, there was a noticeable discrepancy between the estimated foetal Weight (EFW) derived from 2-D biometry (3.63±0.36 kg) and the Actual Birth Weight (ABW) (3.76±0.34 kg). The mean 3-D thigh volume (126.78±8.19 cm3) was higher than the 2-D multi-planar thigh volume (115.18±22.32 cm3), suggesting that 3-D capture accounts for more soft tissue mass. This provides the initial evidence of the 2-D underestimation bias.

Table 1: Summary of descriptive Statistics of the foetal thigh Volume measurements from obstetric ultrasound scan

Parameters	N	Mean±Std	Minimum	Maximum	Range
Gestation weeks	150	38.46±1.12	36.20	40.50	4.30
2D Thigh Volume Value	150	115.18±22.32	82.79	150.20	67.41
3D Thigh Volume Value	150	126.78±8.19	103.52	141.29	37.77
EFW	150	3.63±0.36	2.60	4.81	2.21
ABW	150	3.76±0.34	3.00	5.10	2.10

Keys: 2D=2-dimensional, 3-D=3-dimensional, EFW=Estimated foetal weight, ABW=Actual birth weight

Correlation of 2-D Foetal Thigh Volume against Actual Birth Weight (ABW)

Figure 1 demonstrates a significant positive correlation (r = 0.504, p < 0.001). This indicates that 2-D multi-planar thigh measurements provide a good reliability grade for predicting birth weight though with a wider dispersion of the data points compared to volumetric methods.

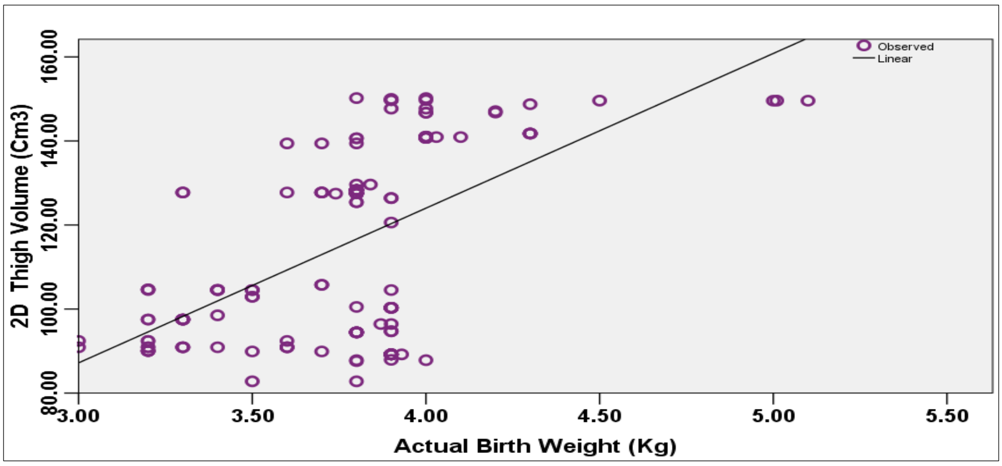

Figure 1: Scatter plot of two dimensional foetal thigh volumes against actual birth weight

Correlation of 3-D Foetal Thigh Volume against Actual Birth Weight (ABW)

3-D thigh volume was correlated with Actual Birth Weight. As shown in figure 2, a Scatter plot illustrates the relationship between 3-D foetal thigh volume (cm^3) and actual birth weight (kg) (n=150). The scatter plot demonstrates a strong, positive linear correlation between the three dimensional volumetric measurements of the foetal thigh and the actual weight recorded at birth. The data points are closely clustered around the regression line, which indicates a high degree of consistency in the measurements across the study population. A Pearson correlation coefficient (r) of 0.589 and a significant level of $p < 0.001$, this figure proves that 3-D thigh volume is a statistically significant predictor of neonatal weight. Notably this correlation is stronger than that observed for 2-D measurements, suggesting that capturing the bulk of the soft tissue mass using semi-automated virtual organ computer aided analysis provides a more accurate presentation of the total foetal mass. The upward slope of the regression line indicates that as the volumetric capacity of the foetal thigh increases, there is corresponding and predictable increase in birth weight. The finding supports the tissue mass theory, confirming that in the late third trimester (36-40weeks), the thigh serves as a primary reservoir for fat deposition. Consequently, the 3-D volumetric model shown in this figure offers a superior alternative to traditional skeletal-based biometry (like femur length) for identifying cases of macrosomia or intra-uterine growth restriction in the south Eastern Nigerian population (Figure 2).

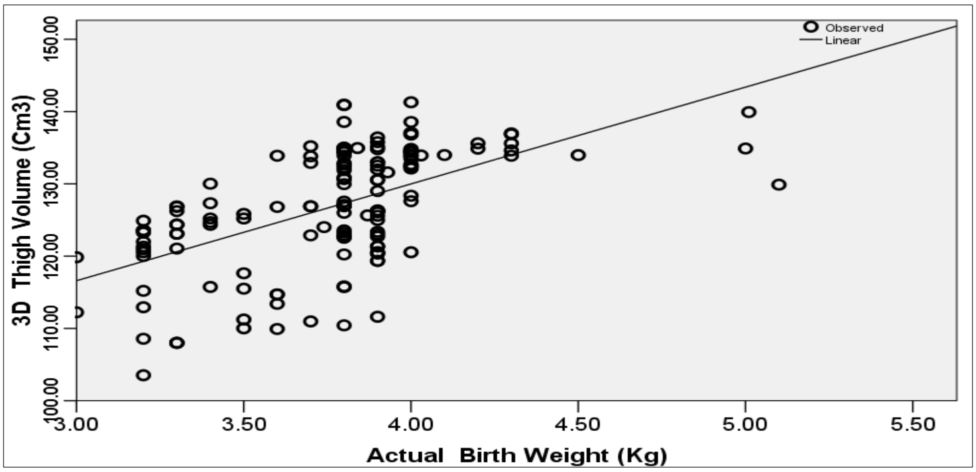

Figure 2: Scatter plot of three-dimensional foetal thigh volumes against actual birth weight

Accuracy of Multi-Parameter 2-D Method against Actual Birth Weight

To satisfy the third objective of the study, the agreement between the Hadlock iv (2-D) method and actual birth weight was evaluated. To assess the clinical reliability of the weight estimation, a Bland-Altman plot was generated (Figure 3). This analysis provides a more rigorous evaluation of agreement than simple correlation. The analysis reveals a systematic bias where the EFW underestimates the ABW by an average of -0.12 kg (120g) and the 95% Limits of Agreement range from -0.48 kg to +0.23 kg. This confirms the problem statement in Chapter 1 regarding 2-D underestimation. This systematic underestimation aligns with the recent findings of Siemer *et al*., (2008), who reported that 2-D biometry consistently lags behind actual birth weight as foetal mass increases. The majority of the data points fall within these limits, indicating acceptable agreement. However, the negative bias suggests that clinicians in this locality should be cautious of potential underestimation when using 2-D Hadlock parameters. This justifies the clinical need for the 3-D models developed in this study to correct this lag in the Nigerian population.

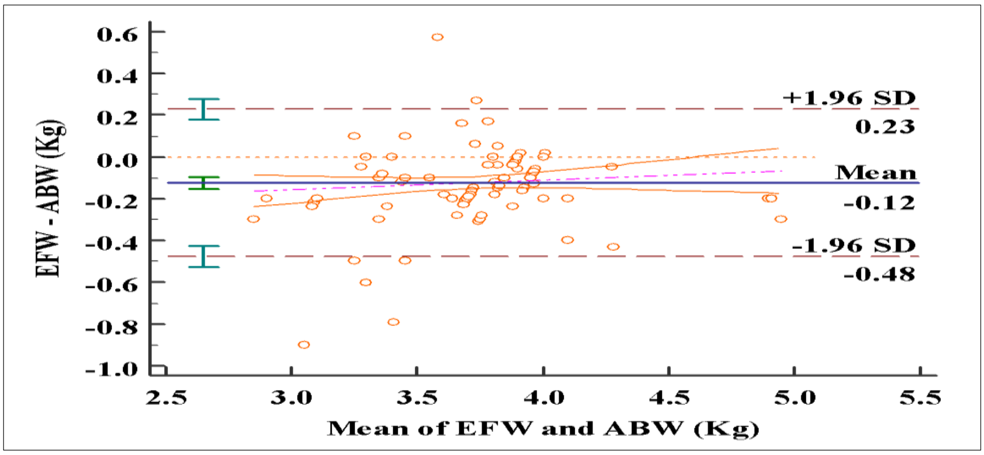

Figure 3: Bland-Altman plot showing agreement between EFW and ABW

Development of Regression Equations and Novel Prediction Models

In fulfilment of objectives 4 and 5, a relationship was established separately between 2-D and 3-D measurements with actual foetal weight, which resulted in two regression equations.

Equation 1: 2-D Thigh Model: Y (EFW) = 2.531 + 0.010 × (2-D ThV)

Equation 2: 3-D Thigh Model: Y (EFW) = 0.354 + 0.026 × (3-D ThV).

Additionally, Equation 3: (3-DThV = 94.947 + 0.276 x 2-DThV) with R^2 value of 0.567 was developed to allow clinicians to approximate 3-D volumes using standard 2-D equipment. This equation will bridge the gap of scarcity of 3-D ultrasound equipment in this locality. The visual evidence for these objectives is provided through a sequence of regression plots.

Figures 4 evaluates the predictive reliability of 2-D-derived foetal thigh volume for the birth weight estimation. The data shows a statistical significant positive correlation coefficient of r= 0.504. The regression analysis produced the predictive equation : (EFW)=2.531 + 0.010 × (2-D ThV) with an R^2 value approximately 0.254.

Figure 5 evaluates the predictive reliability of 3-D volume foetal thigh measurement for weight prediction. It represents the correlation between 3-D foetal thigh volume and actual birth weight. This relationship demonstrated a stronger predictive capacity than the 2-D model, yielding a correlation coefficient of r = 0.589. The corresponding predictive equation for this model is:

(EFW) = 0.354 + 0.026 × (3-D ThV) with R^2 value of 0.347.

Figure 6 is a scatter diagram that demonstrates the correlation between 2-D multi-planar foetal thigh volume measurements and 3-D reconstructed foetal thigh volumes. The figure validates the bridge regression model (3D ThV = 94.947 + 0.276 X 2D ThV) developed in this study. It shows significant positive correlation (r=0.567, $p < 0.001$) providing empirical justification for using accessible 2-D parameters to approximate 3-D volumetric data. This is a critical finding for clinical settings in Anambra State, where 3-D ultrasound equipment may be unavailable. It suggests that 2-D linear dimensions can mathematically be transformed into reliable volumetric estimates.

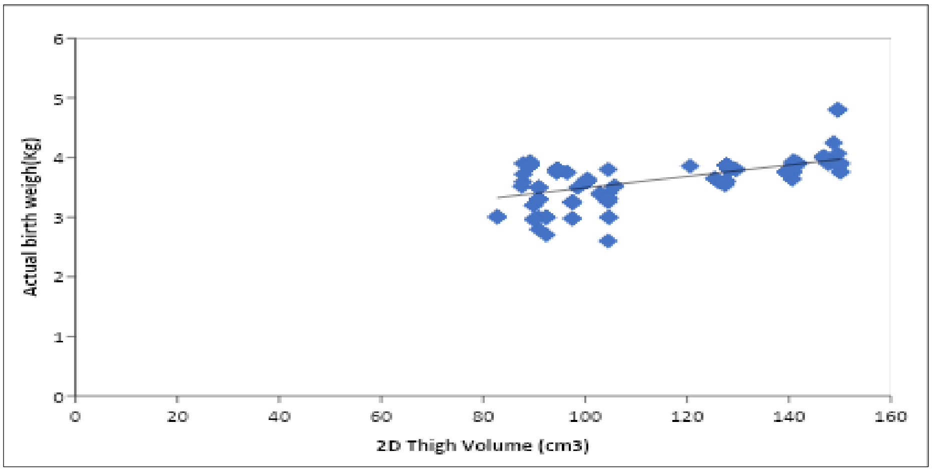

Figure 4: A graph of Actual birth Weight against 2-D thigh volume with a predictive equation for EFW

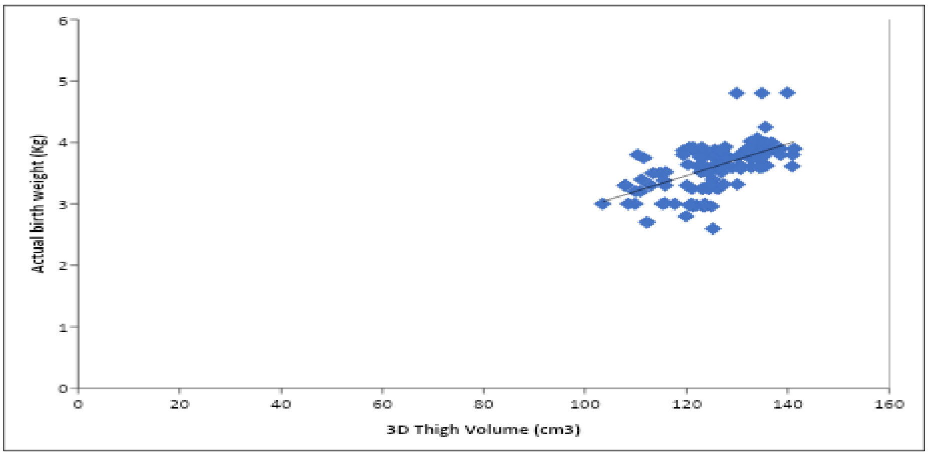

Figure 5: A graph of Actual birth Weight against 3-D thigh volume with a predictive equation for EFW

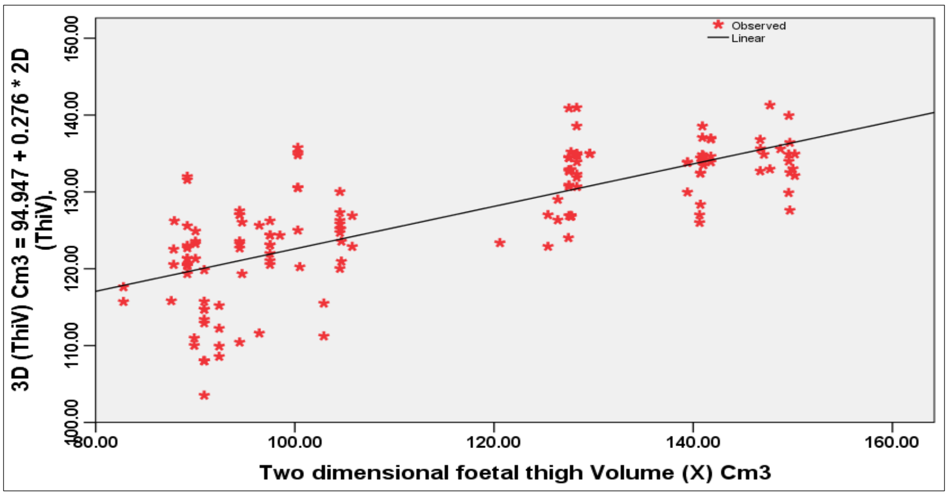

Figure 6: Scatter diagram shows the correlation between the three dimensional foetal thigh volume (Y) with two dimensional foetal thigh volumes (X)

DISCUSSIONS

We observed a good positive correlation between traditional 2-dimensional thigh linear measurements and actual birth weight. However, this correlation was the weakest among the biometric predictors. This can be ascribed to the inherent limitation of 2-dimensional ultrasound, which relies on a single plane and assumes a perfectly cylindrical shape for the thigh, which is also noted by Mgbafulu *et al.,* [15]. According to Mgbafulu *et al.,* [15], 2-dimensional parameters often overlook the irregular distribution of soft tissue in the Nigerian phenotype, explaining why linear measurements alone does not provide a better representation of total foetal mass.

With regards to the reliability of 3-dimensional volumetric, this shows a superior correlation compared to the 2-dimensional method. This justifies the study's premise that 3-dimensional VOCAL technology is more sensitive to neonatal adiposity. By capturing the bulk of the thigh rather than just its length or width, the 3-dimensional method accounts for the subcutaneous fat deposits that accumulate in the late third trimester. This finding is consistent with the finding of the study conducted by Song *et al.,* [7], which also proved that 3-dimensional foetal thigh volume significantly reduces residual error by capturing the actual volume of the soft tissue.

In the comparison of the traditional Hadlock IV formula (BPD, HC, AC, FL) against the actual birth weight, the Bland-Altman analysis revealed a systematic mean bias, confirming that the multi-parameter 2-dimensional approach consistently underestimates birth weight in this population. This underestimation is critical for obstetric management in Anambra State, as it suggests that many ‘at-risk’ macrosomic foetuses may be misclassified as being within a normal weight range. This results in agreement with the findings of the study carried out by Malaviya *et al.,* [6], which reported that 2-dimensional formulas exhibit a central tendency bias that fails at the weight extremes.

Furthermore, this work focused on creating localized mathematical tools for the Nigerian context. The derivation of the regression equation provides an ethnically-specific nomogram that outperformed generalized western models. The regression model developed to predict 3-dimensional volume from 2-dimensional parameters is perhaps the most significant practical finding. This fulfills the objective of resource optimization, allowing clinicians in facilities without 3-dimensional hardware to approximate volumetric accuracy. This addresses the scarcity of equipment noted in Section 2.4 and provides a roadmap for strategic navigation in local diagnostic practice.

The relationship between 2-D foetal thigh volume and the actual birth weight shows a statistically significant positive correlation, with a Pearson correlation coefficient indicating that multi-planar foetal thigh volume accounts for 25.4% of the variance in the actual weight at birth. The correlation relationship between 3-D foetal thigh volume and actual birth weight demonstrated a stronger predictive capacity than the 2-D model, yielding a correlation indicative of superior performance. It implies that 3-D volumetric foetal thigh volume explains 34.7% of the variance in actual birth weight. This confirms that while 2-dimensional ultrasound remains a valuable clinical tool, it exhibits a consistent underestimation of birth weight in the late third trimester within the studied population. The inclusion of foetal thigh volume, particularly when measured using 3-dimensional techniques, significantly enhances the reliability of foetal weight prediction. The higher correlation of 3-dimensional thigh volume with actual birth weight proves that volumetric assessment is a more sensitive indicator of foetal nutritional status and overall mass than traditional linear biometry. This supports the research objective of demonstrating that advanced volumetric imaging reduces the margin of error in foetal weight estimation.

CONCLUSIONS

This research evaluated the comparative accuracy of two dimensional (2-D) and three-dimensional (3-D) ultrasound measurements of foetal thigh volume as predictors of actual birth weight within a south-Eastern Nigerian population. The study successfully addressed the limitations of conventional biometry, which often fails to account for the soft tissue and nutritional status of the fetus in the late third trimester. The findings led to the following definitive conclusions:

1. 3-D volumetric assessment using the semi-automated virtual Organ Computer aided analysis technique is a significantly more reliable predictor of birth weight than 2-D multi-planar measurements. By accounting for the bulk of the thigh and subcutaneous fat deposit, 3-D volumetry offers a more comprehensive representation of total foetal mass, effectively reducing the margin of error in weight estimation. Although the 2-D model remains a clinically, useful alternative when 3-D technology is unavailable.
2. Identification of systemic bias and regional differences: The study conclusively identified the underestimation bias within the conventional 2-D Hadlock iv formula when applied to the local population. The development of a localized, tissue-based model serves as a necessary corrective measure, providing a more ethnically sensitive diagnostic standard. This shift is critical for early and more accurate identification of macrosomia, thereby reducing the risks of undiagnosed obstructed labour and improving overall obstetric safety in the south Eastern region.
3. The development of a locally sensitive prediction regression model. This allows for the mathematical conversion of accessible 2-D parameters into 3-D volumetric estimates. The finding is critical for resource-constrained clinical settings in Anambra State and across Nigeria, where 3-D ultrasound equipments may not be readily available.

Conflict of Interest: There was no conflict of interest declared among the authors

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