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ORIGINAL ARTICLE

Five-dimensional long bones biometry for estimation of femur length and fetal weight at term compared to two-dimensional ultrasound: a pilot study

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ABSTRACT

Background/objective: This study aimed to evaluate accuracy of five-dimensional long bones (5D LB) compared to two-dimensional ultrasound (2DUS) biometry to predict fetal weight among normal term women.

Methods: Fifty six normal term women were recruited at Ain Shams Maternity Hospital, Egypt from 14 May to 30 November 2015. Fetal weight was estimated by Hadlock's IV formula using 2DUS and 5D LB. Estimated fetal weights (EFW) by 2DUS and 5D LB were compared with actual birth weights (ABW).

Results: Mean femur length (FL) was 7.07 ± 0.73 cm and 6.74 ± 0.67 cm by 2DUS and 5D LB ($p = .02$). EFW was 3309.86 ± 463.06 g by 2DUS and 3205.46 ± 447.85 g by 5D LB ($p = .25$). No statistical difference was observed between ABW and EFW by 2DUS ($p = .7$) or 5D LB ($p = .45$). Positive correlation was found between EFW by 2DUS, 5D LB, and ABW ($r = 0.67$ and 0.7; $p < .001$). There was strong agreement between FL measured by 2DUS and 5D LB (ICC = 0.78), and perfect agreement between EFW by 2DUS and EFW by 5D LB (ICC = 0.918). 2DUS and 5D LB showed mean absolute percentage error for EFW of 10 ± 7% and 8 ± 7% compared to ABW ($p = .15$).

Conclusions: 2DUS and 5D LB had same accuracy for fetal weight estimation at normal term pregnancy.

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KEYWORDS
2DUS; 5D LB; fetal femur; fetal weight; five-dimensional long bones

Plain English summary

Accurate prediction of fetal weight is of high priority for obstetricians, as it affects decisions for management of fetuses with abnormal weights (intrauterine growth restriction and macrosomia); therefore, affecting neonatal mortality and morbidity. Five-dimensional long bone (5D LB) was innovated for reconstruction of images of femur length (FL) and performing fetal biometry. It can provide an automatic detection, reconstruction, and measurement of fetal long bones (LB) particularly the femur from volume data obtained by three-dimensional ultrasound (3DUS). This was a cross-sectional prospective observational study conducted at Ain Shams Maternity Hospital, Cairo, Egypt from 14 May 2015 to 30 November 2015. Fifty six women at 37–41 weeks of gestation with singleton fetuses were enrolled in the study and planned for elective delivery by cesarean section or induction of labor. FL measured by 2DUS was 7.07 ± 0.73 cm and by 5DLB was 6.74 ± 0.67 cm which showed statistically significant difference ($p = .02$). The current study shows that 2DUS and 5D LB had the same accuracy in fetal weight estimation at term pregnancy.

Background

Prediction of fetal weight entails the indirect measurement of fetal biometry by ultrasound that is then introduced into formulae to calculate an estimation of fetal weight. Initially, one dimension of the fetal head was used [1]. Later on, significant improvements of ultrasound machines made it possible for two-dimensional measurements, where biometry of fetal abdomen along with the fetal head improved fetal weight estimation

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[2]. Hadlock et al. [3] made a further innovation by measuring FL and furthermore, they introduced different formulae, including biometry of the fetal femur, head, and abdomen [4]. Various formulae for estimation of fetal weight were introduced recently however they are still not accurate enough [5,6] and Hadlock formulae remain the most reliable of all [7–9].

Accuracy of measurement of fetal biometry is crucial for accuracy of prediction of fetal weight even when using a valid formula [10]. Long bone measurements particularly the femur is generally easy to isolate by ultrasound but there are some limitations during their measurements. Distal ends of LB are difficult to be isolated due to the presence of paired bones like tibia and fibula. Sudden fetal movements, fetal position at time of scan, maternal obesity and anterior placenta, also, compromise the scan [11].

Five-dimensional LB was innovated for reconstruction of images of FL and performing fetal biometry. It can provide an automatic detection, reconstruction, and measurement of fetal LB particularly the femur from volume data obtained by 3DUS [11].

The aim of the current study is to evaluate the reliability of 5D LB using 3DUS femur bone biometry compared to two-dimensional ultrasound (2DUS) biometry in prediction of birth weight among pregnant women at term.

Materials and methods

This was a cross-sectional prospective observational study conducted at Ain Shams Maternity Hospital, Cairo, Egypt from 14 May 2015 to 30 November 2015. It is registered under NCT02396654 on 19 March 2015 on clinicaltrials.gov. 56 women at 37–41 weeks of gestation with singleton fetuses were enrolled in the study and planned for elective delivery by cesarean section or induction of labor. Patients with medical disorder with pregnancy like diabetes mellitus or hypertension, fetal congenital anomalies, non-visible fetal parts during ultrasound scan, multiple pregnancies, oligohydramnios, polyhydramnios, and obese patients with BMI $>30\,\text{kg/m}^2$ were excluded from the study. This study conformed to the declaration of Helsinki for ethical medical research. Institutional review and ethical board approval (4 May 2015) were obtained and all participants signed informed written consents.

Gestational age was calculated according to first day of last menstrual period by Naegle's Rule and confirmed by ultrasound measurement of crown rump length between 9 and 12 weeks for all participants. Estimation of fetal weight was done at Fetal Special Care Unit, by the same sonographer (fourth author). 2DUS and 5D LB were done consecutively for all participants who delivered within 48 h. Estimated fetal weight (EFW) by 2DUS and 5DLB were documented and compared with the actual birth weight (ABW) after delivery. Neonates were weighed within 15 min of delivery using a standardized neonatal weighing scale.

2DUS and 5D LB were performed using UGEO WS80A Samsung Medison Ultrasound system; CA1-7A trans-abdominal ultrasound transducer was used for 2DUS and CV1-8A volume transducer was used for 3DUS. Fetal biometry was measured twice and the average was used. EFW was calculated using Hadlock's IV formula [4] which included measurements of the biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and FL.

$$\begin{aligned}&\text{Hadlock IV Formula} =\\&\{\text{Log10 BW} = 0.3596 + (0.00061 * \text{BPD} * \text{AC})\\&\quad + (0.0424 * \text{AC}) + (0.174 * \text{FL}) + (0.0064 * \text{HC})\\&\quad - (0.00386 * \text{AC} * \text{FL})\}\end{aligned}$$

Using 2DUS, FL was measured in a plane where the femur diaphysis was almost parallel to the transducer surface and the medial epicondyle was visible. The measurements were taken from one end of the diaphysis to the other. HC and BPD were measured in the axial view at the level of the cavum septi pellucidi where both thalami were seen symmetrical, and the anterior and posterior aspect of the cerebral falx was equidistant to the parietal bones. BPD was measured from the outer edge of the proximal parietal bone to the inner edge of the distal skull table, in a line perpendicular to the cerebral falx. HC was measured using the scanner's automatically generated ellipse including the outer margins of the fetal skull [12]. AC was measured in a transverse circular view of the abdomen at the level of the stomach and porto-umbilical complex using the scanner's automatically generated ellipse including the outer margin of the outline of the transverse view of the abdomen.

Using 5D LB, automated measurement of FL was done using the three-dimensional (3D) volume probe; FL was detected as in 2DUS, then the femur was included in a volume box so that the bone length occupied 80% of the image, which was captured using 3D scan in longitudinal-90 (long-90) set (Figure 1(A)). Hur et al. [11] studied the variability and agreement between measurements of femur long-90 and femur long-45 taken by manual 3DUS and 5D LB. There was no significant difference between both measurements yet the scanning angles showed intraclass correlation

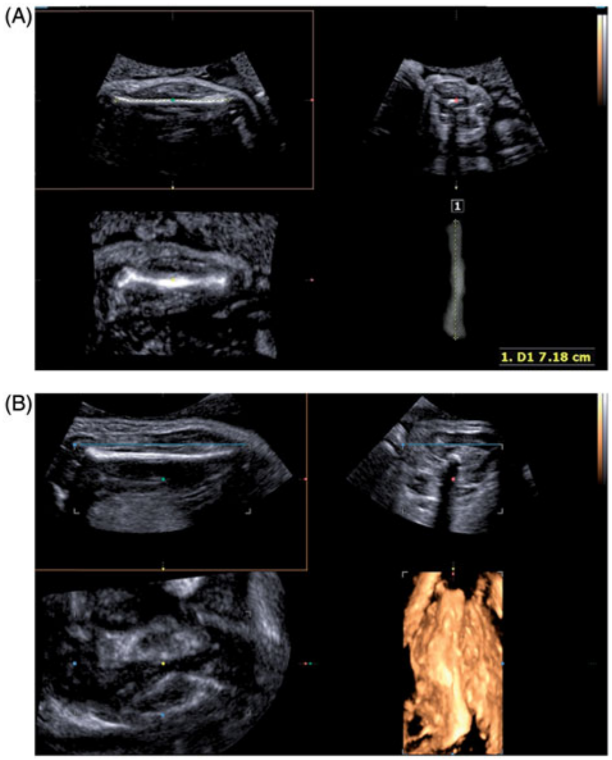

Figure 1. (A) Detection of the femur length by 3DUS volume probe. (B) Automated measurement of the femur length by 5D LB set key.

(ICC) > 0.9 which indicated a high level of agreement. Therefore, femur long-90 measurements were used in the current study. Appropriate plane was detected for FL measurement, then the length was measured using 5D LB in the following steps; the volume data obtained by the 3DUS measurement were displayed in an offline mode and the 5D LB key was pressed where the software automatically analyzed and reconstructed the 3D image of the femur. The FL measurement was displayed on the screen (Figure 1(B)). FL measurement acquired by the 5D LB set key was edited in the report table and then the ultrasound machine calculated EFW using Hadlock's IV formula.

A sample size of at least 22 subjects with two observations per subject achieves 80% power to detect an intra-class correlation of 0.50 under the alternative hypothesis when the intra-class correlation under the null hypothesis is 0.00 using an *F*-test with a significance level of 0.05 [13].

Statistical analysis of data was done by IBM computer using SPSS (version 16; IBM SPSS Statistics, Armonk, NY). Quantitative data were presented as minimum, maximum, mean, and standard deviation. Qualitative data were presented as count and percentage. Paired sample *t* test was used to compare between means of paired observations. 95% confidence interval (CI) and statistical significance were expressed as *p* values. *p* Value $<.05$ was considered statistically significant.

Pearson correlation test was used to compare correlation between different continuous variables and ICC was used to measure agreement between them ($r > 0.7$ means strong correlation). Degree of agreement was determined by method of Bland and Altman. *F*-test is a test with null hypothesis that the true value of ICC = 0. Average measures ICC is calculated and states reliably the group of raters agree (representing estimate of the reliability if the results were averaged by the two methods). Single measures ICC states reliability of using one method (2DUS or 5D LB). ICC can be interpreted as follows: 0.7–0.8 indicates strong agreement; and >0.8 indicates almost perfect agreement. In the current study to estimate the accuracy of prediction of fetal weight, errors between the ABW and EFW were calculated using the following equations; Error (*E*)=ABW – EFW, Error percentage (EP) = (ABW – EFW)/ABW, Absolute Error (AE)=absolute value (ABW – EFW), Absolute Percentage Error (APE)=absolute value of (ABW – EFW)/ABW.

Results

Fifty six pregnant women were enrolled. Six women were excluded from the study; three women delivered after 96 h of the ultrasound fetal weight estimation, two women had oligo-hydramnios and one woman had poly-hydramnios. Fifty women were included in the final analysis.

Their average age was 28.1 ± 5 years; average parity was 2 ± 1; average gestational age at time delivery was 39.1 ± 1.2. Fifty six percent of participants delivered by lower segment cesarean sections (LSCS) due to previous cesarean sections and 44% delivered by successful induced vaginal delivery due to prolonged pregnancies.

FL measured by 2DUS was 7.07 ± 0.73 cm and by 5DLB was 6.74 ± 0.67 cm which showed statistically significant difference ($p = .02$). EFW by 2DUS was 3309.86 ± 463.06 g and by 5D LB was 3205.46 ± 447.85 g showing statistically insignificant difference ($p = .25$). Moreover, there was no statistically significant difference when comparing ABW (3282.60 ± 565.32 g) with EFW by 2DUS ($p = .7$) and EFW by 5D LB ($p = .45$) (Table 1; Figure 2).

A significant positive correlation was found between EFW by 2DUS and ABW ($r = 0.67$) and a higher positive degree of correlation existed between EFW by 5D LB and ABW ($r = 0.71$). Both were statistically highly significant ($p < .001$) (Table 2). A positive linear relationship existed between ultrasound fetal weight estimation and ABW (Figure 3).

There was a strong agreement between FL measured by 2DUS and 5D LB (ICC = 0.78). Moreover, there was a perfect agreement between EFW by 2DUS and EFW by 5D LB (ICC = 0.918). Results showed a highly statistically significant relationship ($p < .001$) (Table 3). The Bland–Altman plot shows a fair distribution around the mean of differences in measurements of FL and EFW by 2DUS and 5D LB (Figure 4).

EFW by 2DUS showed a mean APE of 10 ± 7% while 5DLB showed a mean APE of 8 ± 7% compared to ABW with no statistically significant difference ($p = .15$) (Table 4).

Discussion

Accurate prediction of fetal weight is of high priority for obstetricians, as it affects decisions for management of fetuses with abnormal weights (intrauterine growth restriction and macrosomia); therefore, affecting neonatal mortality and morbidity [14–17]. Prediction of fetal weight has always been dependent on input of 2DUS measurements of fetal biometry in models and formulae. These formulae showed errors as high as 20% when EFW was compared with actual birthweights especially in extremes of fetal weights [3,4,18–22]. Regression equations and volumetric formulae were introduced to improve accuracy of fetal weight prediction but still errors of less than 7% are rare [5].

In the current study, mean FL by 2DUS was 7.1 cm and 6.7 cm by 5D LB which was statistically significant, yet EFW by 2DUS was 3309.9 g and 3205.4 g by 5D LB which was statistically insignificant. Comparing ABW (3282.6 g) with EFW by either 2DUS or by 5D LB was also insignificant. A significant positive correlation was found between EFW by both 2DUS and 5D LB with ABW. There was a strong agreement between FL measured by 2DUS and 5D LB (ICC = 0.78). Moreover, there was a perfect agreement between EFW by 2DUS and EFW by 5D LB (ICC = 0.918). Results showed a highly statistically significant relationship ($p < .001$). 2DUS showed a mean APE for EFW of 10 ± 7% while 5D LB showed mean APE of 8 ± 7%. Comparing both APE means was statistically insignificant.

Njoku et al. [23] and Ugwu et al. [24] compared the accuracy of fetal weight estimation by 2DUS using Hadlock's IV and clinical fetal estimation. The mean APE of 2DUS in both studies was 9 ± 7.6% and

Table 1. Comparison between 2DUS and 5D LB regarding femur length (FL) and fetal weight.

	Mean ± SD	T	p Value
FL by 2DUS (cm)	7.07 ± 0.73	0.149	.02
FL by 5D LB (cm)	6.74 ± 0.67		
EFW by 2DUS (g)	3309.86 ± 463.06	0.04	.25
EFW by 5D LB (g)	3205.46 ± 447.85		
ABW (g)	3282.60 ± 565.32	−0.02[a] −0.07[b]	.7[a] .45[b]

SD: standard deviation; 2DUS: two-dimensional ultrasound; 5D LB: five-dimensional ultrasound long bones; *t*: unpaired Student's *t*-test.
[a]EFW by 2DUS versus ABW.
[b]EFW by 5D LB versus ABW.

Table 2. Correlation between actual birth weight (ABW) and estimated fetal weight (EFW).

	Mean ± SD	R	p Value
ABW (g)	3282.60 ± 565.32	–	–
EFW by 2DUS (g)	3309.86 ± 463.06	0.67	<.001
EFW by 5D LB (g)	3205.46 ± 447.85	0.71	<.001

r: Pearson's correlation coefficient.

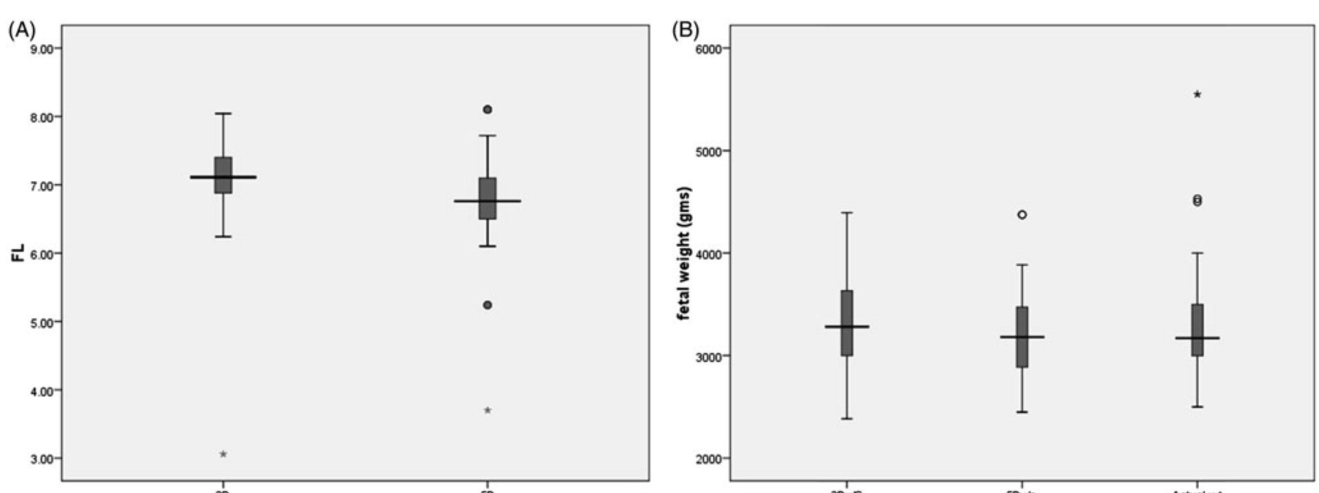

Figure 2. (A) Box plot showing comparison between the femur length measurements by 2DUS and 5D LB. (B) Box plot showing comparison between estimated fetal weight calculated by Hadlock's IV formula by 2DUS, 5D LB, and actual birth weight.

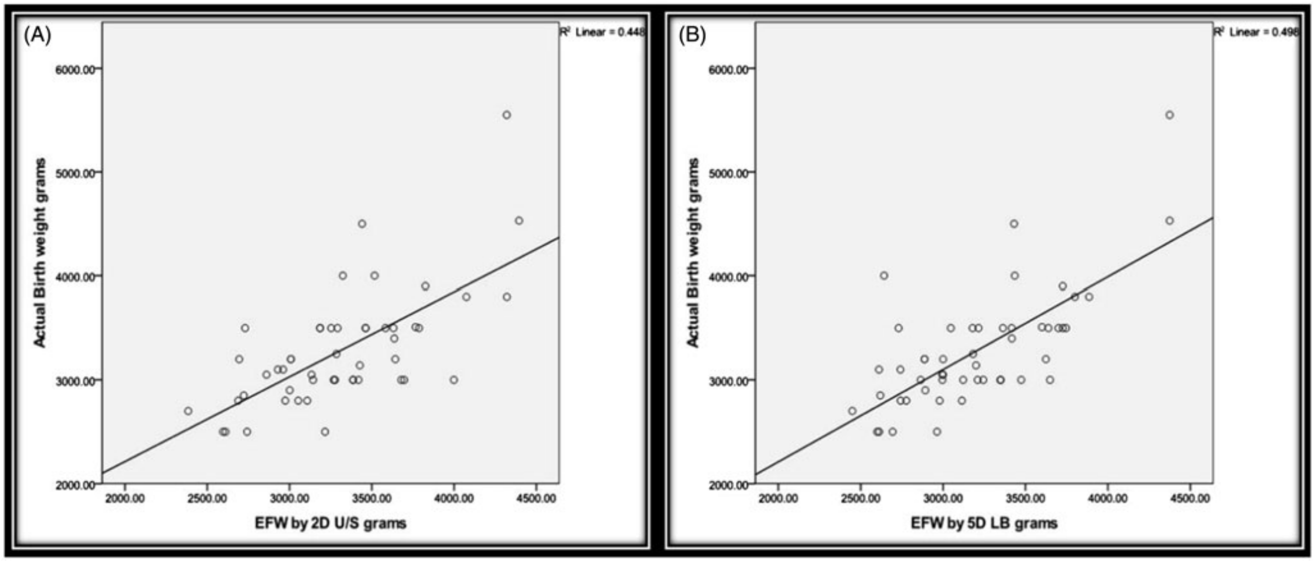

Figure 3. (A) Scatter plot for correlation between actual birth weight (ABW) and estimated fetal weight (EFW) by 2DUS. (B) Scatter plot for correlation between ABW and EFW by 5D LB.

Table 3. Agreement between 2DUS and 5D LB regarding femur length (FL) and estimated fetal weight (EFW) by intra-class correlation coefficient (ICC).

		F test	
	ICC (95% CI)	Value	Significance
FL by 2DUS and 5D LB	0.780 (0.614–0.875)	4.543	<.001
EFW by 2DUS and 5D LB	0.918 (0.856–0.953)	12.179	<.001

CI: confidence interval.

9.97%, respectively. They both showed a positive correlation between EFW by 2DUS and ABW ($r = 0.85$, $r = 0.69$, respectively). In the current study, 2DUS showed a mean APE for EFW of 10 ± 7% and a positive correlation between EFW by 2DUS and ABW ($r = 0.67$), nearly similar to the latter studies.

Oliver et al. [25] studied the accuracy of 2DUS biometry using Hadlock's IV and recruited 305 women at term that had their scans done less than 2 weeks from delivery. Their APE ranged from 6 to 11% with an average of 8.52%. Their conclusion was that the longer the interval from scanning to delivery, the greater was the error between EFW and ABW. In the current study, all patients delivered within 48 h of scanning and the mean APE was 10% for EFW by 2DUS and 8% for EFW by 5DUS LB.

Hur et al. [11] studied LB measurements including the femur by three different methods; 2DUS, 3DUS, and 5D LB, in 39 pregnant women between 26 and 32 weeks of gestation. There was no statistically significant difference between LB measurements by 2DUS, 3DUS, and 5D LB. The ICC for FL measurement between 2DUS and 5D LB was 0.912 showing high level of agreement. In the current study, there was a significant difference between FL measurements by 2DUS and 5D LB. Five-dimensional LB underestimated FL compared to 2DUS but did not affect the accuracy of fetal weight estimation by 5D LB. There are some reasons which might explain the difference in FL measurement observed between 2DUS and 5D LB in the current study. This may be due to failure to detect appropriate sagittal plane to construct a femur image and inability of 5D LB to differentiate between the bone and soft tissue because of low bone echo in some cases. These reasons were also addressed by Hur et al. [11] who also mentioned similar reasons to our current study. Moreover, they also proposed other factors which may explain these differences in LB measurements by 5D LB like image blurring from fetal movements or maternal obesity and acoustic shadowing obstruction of nearby organs or the position of the measured LB. They also measured FL in preterm fetuses between 26 and 32 weeks of gestation where the femur is smaller in size and surrounded by adequate liquor compared to term fetuses in the current study.

There are several strengths for the current study. To our knowledge, it is the first study comparing FL by 2DUS and 5D LB in normal term pregnancy. It is also the first one to address the accuracy of automated measurement of FL by 5D LB in prediction of birth weight using Hadlock's IV formula in term pregnancy. Only one experienced sonographer preformed the ultrasound examination and an average of two measurements was taken, therefore inter-observer variability as well as intra-observer variability was alleviated to a great extent.

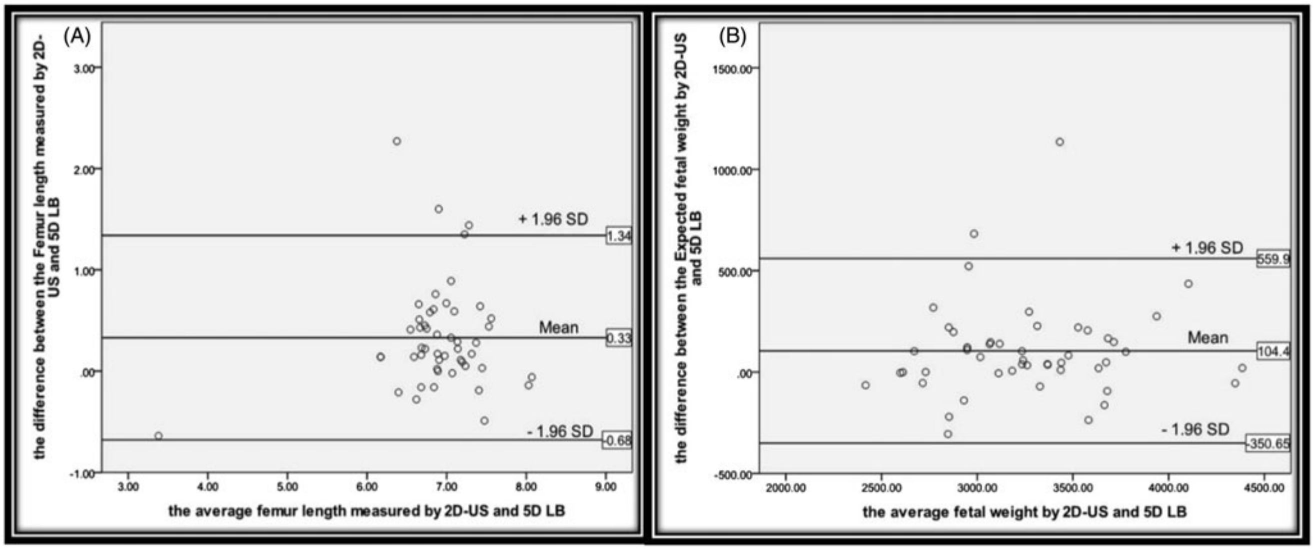

Figure 4. (A) Bland and Altman plot showing variability in femur length (FL) measurement between 2DUS and 5D LB. (B) Bland and Altman plot showing.

Table 4. Comparison of errors between actual birth weight (ABW) and estimated fetal weight (EFW) using Hadlock's IV formula by 2DUS and 5D LB.

	Mean ± SD	Paired *t*-test	*p* Value
Absolute error (AE) by 2DUS	328.54 ± 272.34	–	–
Absolute error (AE) by 5D LB	286.98 ± 291.61	–	–
AE difference between 2DUS and 5D LB	41.56 ± 224.86	1.31	.20
Mean absolute percentage error (APE) by 2DUS	0.10 ± 0.07	–	–
Mean absolute percentage error (APE) by 5D LB	0.08 ± 0.07	–	–
Mean APE difference between 2DUS and 5D LB	0.02 ± 0.07	1.48	.15

Conclusions

The current study shows that 2DUS and 5D LB had the same accuracy in fetal weight estimation at term pregnancy. Although 5D LB showed lower mean FL measurements, this did not compromise fetal weight estimation by 5D LB compared to 2DUS.

Limitations of the study

Although this research was carefully performed, we are still aware of its limitations and shortcomings. Although, the measurement of the FL by 5D LB program is in fact semi-automated as it is still operator dependent. The sonographer has to search for the appropriate plane and the computer then measures automatically through image subtraction, so we are still in need for an innovation in ultrasound technology and 5D LB program to reach a fully automated system, in which the correct plane can be also determined by the machine itself to overcome the measurement errors in FL observed in the current study and to replace entirely conventional 2DUS fetal weight estimation in the future.

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Ethical consideration: Institutional review board (IRB) approval: The protocol was discussed by the ethical scientific committee and informed consent was taken before participation.

Consent procedure: The investigator made a great concern that a correct informed consent process was in place to make sure that potential research subjects were fully addressed about the nature and objectives of this clinical trial, the potential hazards and gains of study participation, and also their rights as research subjects. The investigator took the written, signed an informed consent of each participant before performing any study-specific technique on the participant. The investigator retained the forms of original signed informed consents.

All data and materials are available on request with agreement for publication.

Subject confidentiality: All evaluation forms, reports, laboratory specimens, and other records that leave the site would not comprise unique personal data to maintain subject confidentiality.

Disclosure statement

All the authors declare no conflict of interest.

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