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Efficacy of fetal thigh volumetry in predicting birth weight using the virtual organ computer-aided analysis (VOCAL) technique

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Summary

Objectives: The present study was conducted to compare the accuracy of formulas used to calculate fetal thigh volume (FTV) using the virtual organ computer-aided analysis (VOCAL) technique with two-dimensional (2D) in formulas predicting birth weight. *Materials and Methods:* This was a prospective, cross-sectional study of 84 pregnant women with 72 hours of delivery evaluated at a university hospital between May, 2008 and April, 2010. After 2D ultrasounds (US) measurement, 3DUS was also used to determine FTV with estimates computed using the VOCAL program. *Results:* The correlation between fetal weight predicted by the 3D equation of FTV and the actual birth weight was significant. While FTV and the Hadlock II equation exhibited a low sensitivity for detection of low-birth-weight infants, FTV was a more sensitive method of detecting high-birth-weight infants than the Hadlock II equation. *Conclusions:* It is clear that using 3DUS-VOCAL to measure FTV provides more accurate estimation of fetal birth weight.

Key words: Birth weight; Fetus; Thigh; Ultrasonography; Prenatal.

Introduction

Birth weight is an important variable affecting perinatal mortality [1] and an accurate estimation of birth weight is critical to making an informed obstetric decision. The estimated fetal weight (EFW) calculation has been reported to be the most accurate model of birth weight [2], and is based on head size, abdominal circumference (AC), and femur length (FL). A fetal weight estimating formula that uses two-dimensional (2D) ultrasound (US) to measure common fetal growth indices such as biparietal diameter (BPD), AC, and FL is a part of a routine perinatal examination. However, EFW by 2DUS is relatively inaccurate because of the presence of soft tissue and the fact that it is based on mathematical equations that are operator-dependent [3].

Limb volume is strongly correlated with gestational age, fetal growth, and nutrition [4], and several studies have attempted to use limb circumference and volume to predict birth weight using three-dimensional ultrasound (3DUS). This technique has shown promise as an alternative to 2DUS for birth weight estimation [5, 6]. However, all available data on fetal thigh volumetry (FTV) by 3DUS are based on the conventional multiplanar method, as initially described by Chang *et al.* [5]. There have been limited studies of the usefulness of a new rotational technique, virtual organ computer-aided analysis (VOCAL), for this purpose.

The present study was conducted to assess the accuracy of FTV for prediction of birth weight using the vocal technique compared to the commonly used 2DUS formulae. This study also examined additional maternal parameters, including body weight, body mass index (BMI), and thigh circumference (TC), together with infant body weight and TC.

Materials and Methods

Patients

This was a prospective, cross-sectional study of 84 pregnant women between May 2008 and April 2010 and was approved by Soonchunhyang University Bucheon Hospital Institutional Review Board. All patients provide informed signed consent. Inclusion criteria consisted of a single live fetus with a planned delivery or cesarean section within 72 hours of ultrasonography. Exclusion criteria were multiple pregnancies, intrauterine fetal death at presentation, fetuses with structural malformations detected by ultrasonography or chromosomal anomalies, pregnant women who smoke or suffer from chronic illnesses (diabetes mellitus, hypertension, chronic kidney disease, amongst others), poorly visualized fetal limbs due to technical factors, and oligohydramnios (amniotic fluid index [AFI] below the 5^{th} percentile) or polyhydramnios (AFI above the 90^{th} percentile) [7, 8]. Gestational age was based on the first day of the last menstrual period and confirmed by a first trimester dating scan. Each fetus was included only once. Maternal age, gravidity, BMI, and the presence of obstetric complications were also documented.

2DUS measurements

Before delivery, maternal weight and TC were recorded. All infants were delivered within 72 hours after the ultrasound examinations, and TC was measured within 72 hours of birth. 2DUS

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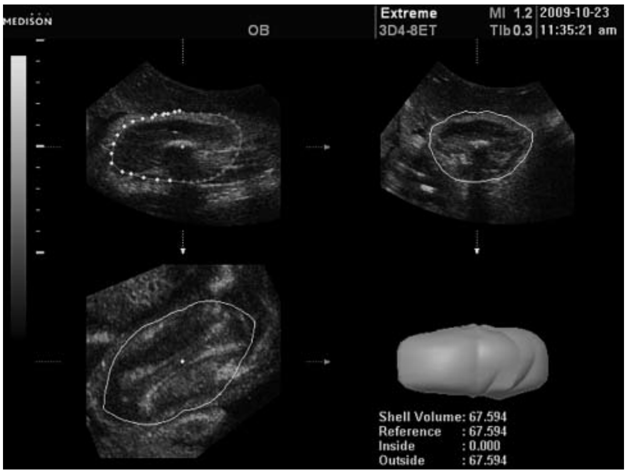

Figure 1. — Fetal thigh volume assessment by three-dimensional ultrasonography.

was also used to measure BPD, AC, and FL. BPD was measured from the outer edge of the proximal fetal skull bone to the outer edge of the distal bone. No correction was made for different shapes of the fetal head in non-vertex presentations. AC was measured in standard transverse planes at the levels of the stomach and umbilical vein-ductus venosus complex. FL was measured from the proximal end of the greater trochanter to the distal metaphysis. The side of the thigh closest to the transducer was used to assess the FL, since no significant difference between the right and left thigh volumes has been reported [9].

3DUS measurements

After 2DUS measurement, 3DUS was also used to acquire FTV using multifrequency (4-7 MHz) convex volumetric transducers (3D4-7EK) on an Accuvix XQ scanner. When the fetus was at rest, the transducer was placed to display the femur diaphysis in the traditional plane for assessing the FL. The 3D volume box was adjusted for the size of the thigh and the sweep angle was set 60°. The slowest sweep velocity at four frames per second was chosen in order to guarantee the best resolution. Several thigh volumes were obtained using automatic sweeps, but only two to four were saved for further analysis. The criteria for further analysis included the absence of motion artifacts and the presence of the entire thigh within the 3D image. Thereafter, the VOCAL program was activated. Fetal thigh images were initially displayed on the ultrasound screen in three orthogonal planes (Figure 1). The sagittal view of the femur in plane A was chosen (top left image) and rotated so that the orientation of the thigh and whole diaphysis was coincident with the y-axis. Two demarcating arrows were positioned at the proximal and distal femoral extremities (echogenic femoral diaphysis), similar to the femoral length method. Plane A was selected in the multiplanar display and used as a reference image. Volumes were calculated utilizing the VOCAL program with a manual trace at 30° of rotation. At the end of the 180° rotation, the computer automatically calculated the volume. Before this calculation was accepted, contouring imperfections were modified in the corresponding axial section exposed in plane C (bottom left image) by repeatedly scrolling up and down. The volume displaying the best quality, in terms of contrast and definition, was selected for estimating fetal weight. All measurements were obtained by a single ultrasound operator.

Table 1. — *Formulas used for fetal weight estimation.*

Fetal parameters	Author	Formula
AC, BPD (cm)	Shepard *et al.* [10] Warsof et al. [11]	Log10 BW (g) = -1.599+0.144 X BPD+0.032 X AC–0.000111 X (BPD2 X AC)
AC, BPD (cm)	Thurnau *et al.* [12]	BW (g) = (BPD X AC X 9.337)–299
BPD, AC, FL (cm)	Hadlock *et al.* [2]	Log10 BW (g) = 1.335–0.0034 X AC X FL+0.0316 X BPD+0.0457 X AC+0.1623 X FL
FC, TV (ml)	Chang *et al.* [5]	BW (g) = 1080.87350+22.44701 X TV

BW = birth weight, AC = abdominal circumference, BPD = biparietal diameter, FL = femur length, FC = fetal thigh circumference, TV = thigh volume.

Table 2. — *Demographic data of the study group.*

Characteristic	Mean ± SD
Maternal age (years)	31.2 ± 4.3
Gravity	2.2 ± 1.1
Height of mother (m)	1.6 ± 0.1
Weight of mother (kg)	67.9 ± 10.8
BMI of mother (kg/m^2)	51.9 ± 23.0
Delivery type	
Normal spontaneous (n)	34
Cesarean (n)	34
Mother's thigh circumference (cm)	51.7 ± 5.4
body weight of newborn (g)	3,025 ± 519
FC (cm)	14.7 ± 1.9
Infants TC (cm)	15.5 ± 1.7
TV (l)	122.9 ± 35.6

FC = fetal thigh circumference, TC = thigh circumference, TV = thigh volume

Calculations

EFW by each formula was calculated separately using the fetal parameters for BPD, AC, FL, and TV, as described in Table 1 [2, 5, 10-12]. All data were collected in a spreadsheet and further analyzed using SPSS for Windows. Maternal age was reported as means ± standard deviation (SD). Other maternal features, such as number of previous gestations, BMI, and TC were documented. Correlation between all measured parameters and actual birth weight was determined by Pearson's correlation coefficient. Regression analysis with correlation coefficients was used to determine the relation between the parameters. The authors compared the sensitivity and specificity of fetal thigh volume formula for prediction of infants ≤ 2.5 and ≥ 3.5 kg with those of the Hadlock II equation. Finally, the significance of differences between EFW and actual birth weight were assessed by paired *t*-tests with a value of $p<0.05$ considered to indicate statistical significance.

Results

The demographic and clinical data of the 84 patients are shown in Table 2. The mean maternal age was 31.2 ± 4.3 years. In the present study, 61.9% of the participants were in their thirties. The actual birth weight ranged from 1.05 to 4.76 kg (mean, 3.03 ± 0.519). Sixty-two infants (73.8%) were considered to be normal weight at delivery. Low-birth-weight infants (< 2,500 grams) were nine (10.7%) and large-birth-weight (> 3,500 grams) infants were 13

Table 3. — *Pearson's correlation between actual birth weight and other sources.*

Parameters	Mean ± SD	Pearson's correlation coefficient (R)	*p* –value
Hadlock II	2,928.7 ± 489.8	0.920	*p*<0.001
FTV	3,841.4 ± 799.8	0.662	*p*<0.001
Mother's weight	67.9 ± 10.8	0.443	*p*<0.001
Mother's BMI	51.9 ± 23.0	0.439	*p*<0.001
Fetus TC	15.5 ± 1.8	0.561	*p*<0.001

FTV = fetal thigh volume, BMI = body mass index, TC = thigh circumference.

(15.5%). As shown in Table 3, the correlation between fetal weight of thigh volume and the actual birth weight predicted by 3DUS was significant (R=0.662, n=84, p < 0.001). Material BMI (51.9 ± 23.0 kg/m^2, R=0.439, p < 0.001) and infant TC (15.5 ± 1.7 cm, R=0.561, p < 0.001) were correlated with actual birth weight. However, 2DUS using the Hadlock II equation predicted actual birth weight more accurately (2,928.7 ± 489.8, R=0.920, p < 0.001). As shown in Figure 2, the scatter plot of actual and estimated birth weight by 3D FTV (A, R^2=0.438) and the Hadlock II equation (B, R^2=0.846) indicates a positive correlation.

Although FTV and the Hadlock II equation showed low sensitivity for prediction of low birth weight, FTV is a more sensitive method for detection of large-birth-weight infants (92.3% *vs.* 46.2%). However, both methods exhibited high specificities for detection of low-birth-weight infants (100% *vs.* 93.3%).

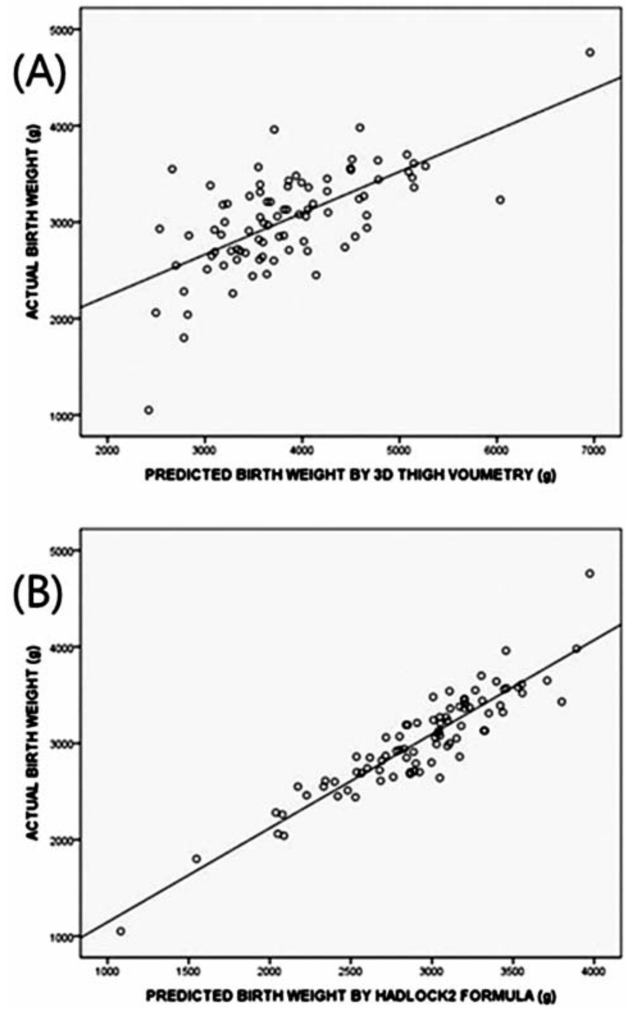

Figure 2. — (A) Scattergram of the thigh volume assessed by three-dimensional ultrasound versus the actual birth weight (Y=0.430X + 1374.828, N=84, R=0.662, p < 0.000). (B) Scattergram of the predicted birth weight by HadlockII equation versus the actual birth weight (Y=0.975X + 169.582, R=0.920 N=84 p < 0.000).

Discussion

The aim of the present study was to determine the accuracy of formulae used to calculate FTV in predicting birth weight compared that of other commonly used formulas composed of BPD, AC, and FL. The authors calculated fetal weight by inputting FTV into the Hadlock II formula developed by Chang *et al.* [5], which uses the multiplanar technique [13]. They also used to the VOCAL technique to demonstrate that FTV is highly correlated with birth weight. They did not record the time necessary to measure fetal biophysics with these techniques but did note that the actual time required to measure FTV by 3DUS was three to five minutes. These findings correspond with those reported previously [14, 15]. When the authors compared the sensitivity and specificity of the 2DUS Hadlock II equation with those of 3DUS FTV for detecting low- or high-birth-weight babies, FTV exhibited a higher sensitivity in detecting high-birth-weight babies than the Hadlock II equation. However, in the birth weight ≤ 2.5 kg category, the Hadlock II equation was more sensitive. After the third trimester it was difficult for both the examiner and the mother to evaluate the whole fetus at one time by ultrasound. Thus, the present data support the superior efficacy of 3DUS in estimating fetal weight close to delivery and suggest that FTV using the VOCAL technique is useful for estimating fetal weight. This is in agreement with another study in which 3D volumetric measurements were performed together with conventional 2D biometry and proved to provide superior results [16].

The authors reviewed the published literature from 2000–2012 in the PubMed database using the keywords '3D ultrasound' and/or 'fetal weight'. A total of 51 papers in English related to 3D ultrasound were retrieved. When studies of solid organs such as the heart, brain, and lung were excluded, only articles related to fetal weight or birth weight remained. The remaining 13 studies are summarized in Table 4. Most examined primarily third-trimester

Table 4. — *Summary of the medical literatures about 3DUS and fetal weight.*

Investigator	Design	Subjects	Major inclusion criteria	Parameter	Results	Comment
Youssef et al. [17] (2012)	Prospective cross-sectional	137	Between 6 - 13^{+6} wks pregnancies, GA = 77.1 ± 14.3 days, CRL = 45.7± 21.8 mm	CRL (2DUS, 3DUS)	GA = 77.1 ± 14.3 days, CRL = 45.7 ± 21.8 mm	3DUS is a highly accurate and reproducible tool for fetal CRL measurement
Lee et al. [18] (2001)	Prospective, cross-sectional	164	Within 4 days of delivery	BPD, AC, FDL, Avol, and Tvol	21.7 - 42.0 wks, Tvol results improved precision of EFW	Tvol can be added to 2DUS measurement to improve precision of EFW.
Lima et al. [19] (2012)	prospective	102		BPD, FL, AC, EFW (Headlock)	No significant systematic error between 2DUS and 3DUS	To confirm the agreement for fetal biometry obtained by 2DUS and 3DUS. 3DUS improved the reliability and agreement of fetal biometry and EFW compared with 2DUS.
Yang et al. [20] (2011)	Prospective, cross-sectional	290 (developmental group ; n=100, validation group ; n=190)	Within 5 days of delivery Hong Kong Chinese women	Tvol, FL, AC, BPD	38.9 ± 3.1 wks, 3346 ± 432 g (n=190), M3 =−2797.107 + 188.708 × BPD + 176.42 × FL + 13.906 × TVol + 57.152 × AC	A new birth-weight prediction model allows better prediction than does the Hadlock models.
Antsaklis et al. [21] (2011)	Pilot	156	Between 11 and 13+6wks GA, CRL : 64.7 ± 8.2 mm (45 - 84 mm), women delivered before 37 or after 42 weeks were excluded	Embryo volume, CRL, Gestational sac volume, placenta volume, birth weight	The embryo volume appears the strongest association with the birth weight at delivery, followed by the CRL, and the gestational sac volume. The placenta volume reveals the most weak association.	Embryo volume measured by 3DUS during first trimester of pregnancy had superior correlation than CRL with the birth weight.
Bennini et al. [22] (2010)	Two-stage prospective, cross-sectional	210 (formula-generating group : n=150, prospective-validation group : n=60)	Delivery within 49 hours after USG measurement	BPD, HC, AC, FL, ThiM, ThiV	38.5 ± 5.8 (29.4 - 42.4) wks, 3247.4 ± 698.3 g (1475-4750), EFW= −562.824 + 11.962 × AC × FDL + 0.009 × BPD^2 × AC^2, EFW = 1033.286 + 12.733 × ThiM, and EFW = 1025.383 +12.775 × ThiV.	There were no significant differences between the accuracies of the new 2D and 3D models in the prediction of birth weight.
Srisantiroj et al. [23] (2009)	Prospective, cross-sectional	176 (Intra-observer reliability test : 20, Formula finding group : 100, Formula evaluating group : 56)	Delivery within 7 days after USG measurement	BPD, HC, AC, FL, Tvol	38.96 ± 2.13 wks, 3,159.64 ± 589.20 gm (n=56), EBW(g) = 774.744 + 32.658 x Tvol (ml)	Compared and validated with the Hadlock's and the Tongsong formula, New formula shows the smallest absolute percentage error (APE), and can improve the accuracy of fetal weight prediction.
Srisantiroj and Maršál [24] (2009)	Prospective, comparative	176	GA ≥ A 287 days, within 4 days of delivery	BPD, HC, AC, FL, Tvol	New formula : FW = 2088.4904 + 81.0519 × HC − 0.1214 × HC2 − 69.0966 × AD + 0.4741 × AD^2 + 6.4044 × Tvol + 0.0534 × Abdvol	The formula of Persson and Weldner (2D) was compared with two 3D formulae (Lee and colleagues). In prolonged pregnancy, new formula is relatively easy to use regardless of weight percentiles or fetal lie.
Srisantiroj and Maršál [24] (2009)	Prospective, comparative	176	Within 4 days of delivery		3938 gm (2740 - 5470), 292 days (289 - 298), FW = 2088.4904 + 81.0519 × HC − 0.1214 × HC^2 − 69.0966 × AD + □0.4741 × AD^2 + 6.4044 × Tvol + 0.0534 × Abdvol	It does not seem reasonable to abandon the 2D ultrasound methods. Because 2D US show same accuracy with 3D US.
Schild et al. [25] (2008)	Prospective, cohort	150	EBW of ≤2000 gm using the Hadlock formula, within 7 days before delivery, BW < 1600 gm		28.5 ± 3.6 wks (18.6 - 36.4 wks), 960 ± 357 gm (260 - 1580 gm), EFW = 656.41 + 1.8321 x volABDO + 31.1981 x HC + 5.7787 x volFEM + 73.5214 x FL + 8.3009 x AC - 449.8863 x BPD + 32.5340 x BPD^2	New formula is relative easy to use regardless of weight percentiles or fetal lie.
Bromley et al. [26] (2007)		27	Only 6 fetus were delivered within 7 days	Fetal presentation, placental location, amniotic fluid volume, fetal biometry,	16 - 20 wks, Trend analysis were not possible.	The evaluation of the 3rd trimester fetus via 3DUS is a reliable method.
Chang et al. [27] (2005)	Prospective, cross-sectional	482 (with IUGR: n=40, without IUGR: n=442)	Taiwanese population, 20 - 40 wks IUGR : classified when their birth weights < 10th percentile for GA, all the fetuses were all followed up to delivery	upper arm volume, common fetal growth parameters (BPD, OFD, HC, AC, and FL), EFW (Hsieh's equation)	The author compared the sensitivity, specificity with upper arm volume and the common fetal biometric indices.	Fetal upper arm volume assessment by 3DUS would be a reliable screening method in fetuses with IUGR.
Schild et al. [16] (2000)	prospective, cross-sectional	190 (formula - finding groups : n =125, formula evaluation group : n = 65)	within 7 days of delivery		Formula-evaluation groups : 36.4 ± 4.1 (23.7 - 41.3) wks. EFW = -1478.557 + 7.242 x thigh volume + 13.309 x upper arm volume + 852.998 x log abdominal volume + 0.526 x BPD^3	The correlation between actual birth weight and fetal weight estimation was highly significant. 3DUS allows superior FEW by including soft tissue volume.

wks = Weeks, GA = gestational age, IUGR = intra-uterine growth retardation, EBW = estimate birth weight, BW = actual birth weight, Avol = arm volume, Tvol = thigh volume, 2DUS = two dimensional ultrasound, 3DUS = three dimensional ultrasound, BPD = biparietal diameter, AC = abdominal circumference, HC = head circumference, FL = femur length, FDL = femur diaphysis length, EFW = estimate fetal weight, VOCAL = Virtual Organ Computer-aided AnaLysis, ThiM = thigh volume measured by multiplanar method, ThiV = thigh volume measured by VOCAL method, AD = abdominal diameter, Abdvo = abdominal volume.

fetuses and showed 3D measurements to have acceptable reproducibility. Like the present study, most manually traced TV measurements, and only one [28] evaluated arm volume measurement and reported greater sensitivity and specificity for a fetus with intrauterine growth retardation (IUGR) than TV. Nine of these 13 studies reported a better result with 3DUS than 2DUS in terms of estimation of fetal weight, while two studies reported no significant difference between 3DUS and 2DUS. One study was not compared due to the small number of cases. Thus, it appears that as the 3DUS technique has advanced, the use of 3DUS in prenatal evaluations is becoming more prevalent [29, 30].

The present study had a number of limitations. For example, the sample size was small and the study was conducted in an obstetric unit of a tertiary care center, which may not be representative of the Korean population. Thus, a large, prospective and multicenter study is necessary to confirm the conclusions of this report.

Conclusions

The authors validated the 3DUS-VOCAL method and reviewed the literature regarding use of 3DUS to estimate fetal birth weight. Based on these results, it is clear that the use of 3DUS-VOCAL to measure FTV will provide more accurate estimations of fetal birth weight and that it has the potential to become an essential prenatal reassessment tool.

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