Original Article

Comparison of the Accuracy of Combined Three-Dimensional Fractional Thigh Volume with Biparietal Diameter and Two-Dimensional Ultrasonographic Biometry for Estimating Fetal Weight at 37 to 42 Weeks of Gestation†

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Objective: To compare the accuracy between the new equation of combined three-dimensional ultrasonography [3D-US] fractional thigh volume [Tvol] with biparietal diameter [cTvol-BPD] and formula of two-dimensional ultrasonography [2D-US] for estimating fetal weight.

Materials and Methods: The prospective cross sectional study was conducted in 251 singleton pregnancies at 37 to 42 weeks of gestation. Sonographic evaluation was performed within 48 hours before delivery. The fetal biometry was performed using 2D-US, while fractional Tvol was performed using 3D-US. The estimated fetal weight [EFW] was calculated using both Hadlock's formula and the new equation from the previous study of Tantechasatid; birth weight (grams) = 1,241.285 + 22.908 Tvol + 43.741 BPD. Paired t-test, Pearson's correlation coefficient and intraclass correlation coefficient [ICC] were used for data analysis.

Results: The mean fetal weight was 3,142.3 grams (SD 387.6). Birth weight calculated from cTvol-BPD and 2D-US were correlated to actual birth weight (r = 0.9 and 0.8, respectively). The mean difference between cTvol-BPD and actual birth weight was 96.6 grams (SD 194.6, $p<0.001$), meanwhile 2D-US was 98.5 grams (SD 283.9, $p<0.001$). Birth weight calculated from new equation was more accurate than Hadlock's formula, ICC 0.8 (95% CI 0.7 to 0.9), $p<0.001$) and 0.7 (95% CI 0.6 to 0.8, $p<0.001$), respectively.

Conclusion: The new equation using combined 3D-US fractional Tvol with BPD was more accurate than 2D-US in estimating fetal weight at 37 to 42 weeks of gestation.

Keywords: Fractional thigh volume, 2-D ultrasonographic biometry, Estimated fetal weight

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Fetal growth restriction [FGR] and fetal macrosomia are among problems commonly found in obstetric practice. These problems indicate high-risk pregnancy that can lead to morbidity and mortality for both fetus and mother. The FGR resulting from uteroplacental insufficiency would lead to poor neonatal outcomes[1,2]. Shoulder dystocia and birth injury could happen with fetal macrosomia and maternal obstetrics maneuvers needed during vaginal delivery. It could also increase cesarean delivery rate[3-5].

Estimating birth weight is a key factor for management planning to reduce risks. Currently, two-dimensional ultrasonography [2D-US] is commonly used to measure biparietal diameter [BPD], head circumference [HD], abdominal circumference [AC], and femur length [FL]. Hadlock's formula has been implemented to use those parameters to estimate fetal weight [EFW][6]. However, there are some errors of those estimated results. It might be because the calculation is based on Caucasian[7]. Diagnosis of an abnormal fetal growth is more difficult. It could overestimate FGR, while underestimating fetal macrosomia[8,9].

Three-dimensional ultrasonography [3D-US] technology have recently been developed. It is now widely used in hospitals. Several studies showed 3D-US of fractional thigh volume [Tvol] correlated well to the actual weight of new born infants[10,11].

Between April 2012 and February 2013, Tantechasatid analyzed pregnant women 37 to 42 weeks of gestation at Bhumibol Adulyadej Hospital and found that fractional Tvol and BPD were two

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strong parameters that were correlated to birth weight. The new technique created a new equation to help EFW for the Thais. The equation is the combination of BPD and fractional Tvol, which EFW (grams) = 1,241.285 + 22.908 Tvol + 43.741 BPD[12]. However, there is still no validation study for this equation. The objective of the present study was to compare the accuracy between this new equation of combined 3D-US of fractional thigh volume with biparietal diameter [cTvol-BPD] and the Hadlock's formula for estimating fetal weight.

Material and Method

A prospective, cross sectional study was conducted in Thai pregnant women 37 to 42 weeks of gestation between October 2015 and July 2016. Those pregnant women also had a high possibility to deliver within 48 hours after ultrasound scan at Bhumibol Adulyadej Hospital. The FGR, fetal macrosomia, and abnormalities in amniotic fluid volume were also included into the study. The exclusion criteria were multifetal gestation, fetuses with major structural or chromosomal abnormalities, fetal death, and incomplete medical data.

The present study was approved by the Ethic Committee, Bhumibol Adulyadej Hospital, Thailand. All pregnant women joined the study were informed about the research protocol and signed consent forms before the study was started.

The authors had to practice 2D-US fetal biometry and 3D-US with an experienced sonographer and the maternal fetal medicine [MFM] staff.

In general, gestational age is calculated from the first day of last menstrual period. It is confirmed again by ultrasound during the first or second trimester of pregnancy.

Formula to calculate the estimate of intraclass correlation coefficients for the group of samples is as following;

$$n = \frac{8Z^2_{\alpha/2}\{(1 - \tilde{\rho}_I)^2 (1 + (k - 1)\tilde{\rho}_I)^2\}}{\{k(k-1)(w)^2\} + 1}$$

where

n = sample size

Z = level of significant, where 0.05 equal to 1.96

k = measurement has to perform 2 times

$\tilde{\rho}_I$ = intraclass correlation coefficient which reviewed from review of literature equal to 0.9[12]

w = half interval width (upper-lower limit) equal to 0.5

After applying the above formula, we needed 228 patients as a group of sample size. Then added up 10% or 23 patients to protect data lost. Therefore, the sample size required was 251 patients.

The authors performed 2D-US with a sample group of 251 pregnant women to find fetal biometry. The 3D-US was used to find fractional Tvol by using Voluson 730 pro (GE, medical system, USA) with hybrid mechanical curved array abdominal ultrasonic transducers (RAB4-8P, RAB2-5P).

The 3D-US for fractional Tvol was performed in sagittal plane (the same plane as FL). Then, picture from that plane was re-opened with 4D view software (version 10.5 BT12 Ext1, GE medical system). Color filtering, brightness, and contrast adjustments were made to have a clear view of soft tissue. Then calipers were put from the middle proximal end of femur to the middle distal end of femur. After that, the software created five pictures with transverse plane. Each picture combined a view of fetal bone, muscle, fat, and skin. Then, the author had to trace the line at the outer border of the fetal skin. This had to be done for the five pictures. The volume from fractional Tvol was shown in cubic centimeters (cm^3).

To find fetal weight, the author calculated the data by using four parameters from fetal biometry according to Hadlock's formula. The author also used the volume from the fractional Tvol and BPD to find the fetal weight according to Tantechasatid's equation; Birth weight (grams) = 1,241.285 + 22.908 Tvol + 43.741 BPD.

After delivery, the new born infant was weighed within 30 minutes using the same scale that was calibrated every three months.

Statistical analysis

SPSS software for window version 16.0 was used to analyze the data. Paired t-test was used to analyze data with continuous normally distributed variables and mean difference between predicted birth weight and actual birth weight. Estimating of intraclass correlation coefficient [ICC] was used to calculate sample size. Pearson's correlation coefficient was used to find correlation between cTvol-BPD equation, Hadlock's formula and actual birth weight. ICC was calculated the accuracy of birth weight prediction of both Hadlock's formula and cTvol-BPD equation. A *p*-value smaller than 0.05 was considered as statistically significant.

Results

Two hundred fifty-one pregnant women were enrolled in the present study. They all had ultrasound scan within 48 hours before delivery. Table 1 demographic data shows the means of this group. The mean maternal

age was 28.6 years old, the mean gestational age was 38.6 weeks, the mean birth weight was 3,142.3 grams, and the mean interval of time between having ultrasound scan and delivery was 23.5 hours. Two hundred thirty-one fetuses born weighed between 2,500 and 3,999 grams, 14 fetuses weighed under 2,500 grams, and six fetuses weighed 4,000 grams or more.

The predicted birth weight calculated from cTvol-BPD equation was strongly correlated to actual birth weight (r = 0.9, p<0.001), and predicted birth weight from Hadlock's formula was also correlated to actual birth weight (r = 0.8, p<0.001) as shown in Table 2.

The mean difference between birth weight from cTvol-BPD equation and actual birth weight was 96.6 grams (SD 194.6) with a mean percentage of error of 5.2%. The mean difference between birth weight from Hadlock's formula and actual birth weight was 98.5 grams (SD 283.9) with a mean percentage error of 7.2%. The mean absolute percentage error between cTvol-BPD and actual birth weight (5.7±3.9) was less than Hadlock's formula (7.6±5.7) (Table 3).

Analysis of accuracy for birth weight prediction found that cTvol-BPD equation ICC was 0.8 (95% CI 0.7 to 0.9), while Hadlock's formula ICC was 0.7 (95% CI 0.6 to 0.8). This result showed that cTvol-BPD equation is more accurate than Hadlock's formula when compared with actual birth weight (Table 3).

In an analysis of the correlation between actual birth weight and predicted birth weight from Scattergram, the birth weight from cTvol-BPD equation showed closer to actual birth weight than birth weight from Hadlock's formula (r^2 = 0.8 and r^2 = 0.6, respectively) (Figure 1, 2).

When categorizing groups according to actual birth weight, the most accurate cTvol-BPD equation was the group with birth weight of 4,000 grams or more, and then 2,500 to 3,999 grams (ICC 0.9, 0.9, respectively). Hadlock's formula offered the most accurate birth weight for the group between 2,500 to 3,999 grams, followed by less than 2,500 grams (ICC 0.8, 0.4, respectively) (Table 4).

The diagnostic accuracy of cTvol-BPD equation and Hadlock's formula for birth weight estimation are shown in Table 5 and 6. The cTvol-BPD equation yielded higher sensitivity and accuracy, especially in birth weight of 4,000 grams or more.

Table 1. Demographic data and obstetric characteristic (n = 251)

Characteristics	Mean ± SD or number (%)
Age (years)	28.6±6.2
BW (kg)	70.8±13.2
Height (m)	1.6±0.1
BMI (kg/m^2)	28.3±4.8
Parity	2.2±1.1
GA (week)	38.6±1.1
Interval between US and delivery (hours)	23.5±8.7
Delivery mode	
Vaginal delivery	63 (25.1)
Caesarean delivery	187 (74.5)
Vacuum extraction	1 (0.4)
Gender	
Male	136 (54.2)
Female	115 (45.8)
BPD (cm)	9.1±0.4
Fractional Tvol (cm3)	61.4±15.3
Birth weight (gm)	3,142.3±387.6
<2,500	14 (5.6)
2,500 to 3,999	231 (92.0)
≥4,000	6 (2.4)

BMI = body mass index; BPD = biparietal diameter; BW = bodyweight; GA = gestational age; Tvol = thigh volume; US = ultrasound

Table 2. Correlation between cTvol-BPD equation, Hadlock's formula and actual birth weight

Methods	r	p-value
cTvol-BPD	0.9	<0.001
Hadlock's formula	0.8	<0.001

cTvol-BPD = combined three-dimensional ultrasonography [3D-US] of fractional thigh volume with biparietal diameter

Table 3. Comparison of cTvol-BPD equation and Hadlock's formula finding

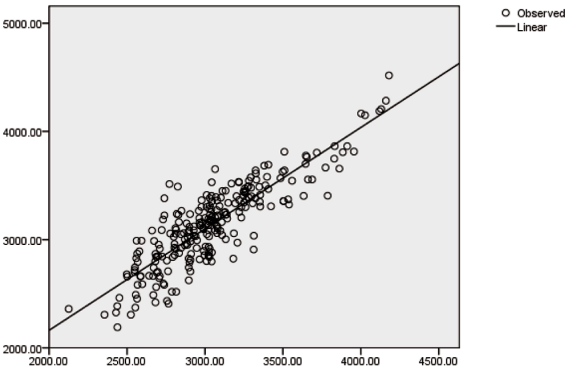
Sonographic finding	cTvol-BPD mean ± SD	Hadlock's mean ± SD
Predicted weight (grams)	3,045.3±358.4	3,043.5±426.4
Mean difference (grams)	96.6±194.6	98.5±283.9
Mean percentage error (%)	5.2±6.3	7.2±8.7
Mean absolute error (grams)	178.2±124.0	229.7±193.3
Mean absolute percentage error (%)	5.7±3.9	7.6±5.7
p-value	<0.001	<0.001
ICC (95% CI)	0.8 (0.7 to 0.9)	0.7 (0.6 to 0.8)

cTvol-BPD = combined 3D-US of fractional thigh volume with biparietal diameter; ICC = intraclass correlation coefficient

Table 4. Comparison of ICC between cTvol-BPD equation and Hadlock's formula in different weight group

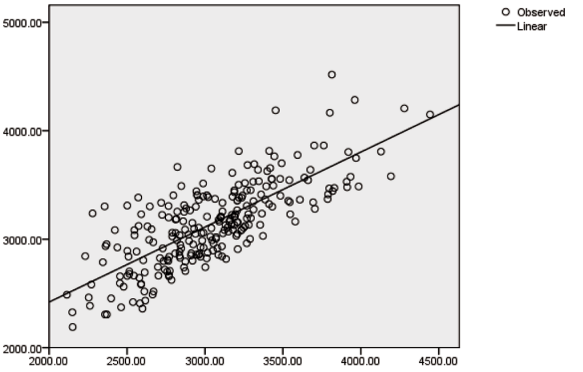
Birth weight	n	ICC for cTvol-BPD	ICC for Hadlock's
<2,500 g	14	0.5 (0.5 to 0.8)	0.4 (0.3 to 0.7)
2,500 to 3,999 g	231	0.9 (0.9 to 0.9)	0.8 (0.7 to 0.8)
≥4,000 g	6	0.9 (0.9 to 0.9)	0.4 (0.3 to 0.8)

cTvol-BPD = combined 3D-US of fractional thigh volume with biparietal diameter; ICC = intraclass correlation coefficient



X = actual birth weight, Y = estimated birth weight from cTvol-BPD equation

Figure 1. Comparison between actual birth weight and cTvol-BPD equation.



X = actual birth weight, Y = estimated birth weight from Hadlock's formula

Figure 2. Comparison of actual birth weight with Hadlock's formula.

Discussion

To reduce the morbidity and mortality of new born infant suspected of abnormal growth, preterm birth, or in cases of pregnancy with complications, getting an accurate fetal weight estimation is very important. Many studies found that fractional Tvol correlated to actual birth weight and when combined with 2D-US measurements of head and trunk, could improve the precision of fetal weight estimation[13].

The authors compared the accuracy of the new equation cTvol-BPD generated by Tantechasatid and Hadlock's formula for estimating fetal weight. All cases were term pregnancy, demographic data, and baseline obstetric characteristic were similar to the previous studies.

The authors found that fractional Tvol was correlated with actual birth weight (r = 0.9) and this result was similar to the previous studies of Srisantiroj et al (studied in all of fetuses that expected to deliver within seven days after ultrasound measurement) (r = 0.965)[12], Tantechasatid (r = 0.96)[12], and Chang et al (studied in all infants that delivered within 48 hours

Table 5. Diagnostic accuracy of cTvol-BPD equation for birth weight estimation

Birth weight	n	cTvol-BPD						
		Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95% CI)	LR+ (95% CI)	LR- (95% CI)
<2,500 g	14	85.7 (42.1 to 99.6)	96.7 (93.6 to 98.6)	42.9 (17.7 to 71.1)	99.6 (97.7 to 100.0)	96.4 (95.2 to 98.1)	26.1 (12.4 to 55.1)	0.2 (0.0 to 55.1)
2,500 to 3,999 g	231	96.6 (93.5 to 98.5)	92.3 (64.0 to 99.8)	99.6 (97.6 to 100.0)	60.0 (36.1 to 80.9)	96.4 (94.5 to 97.9)	12.6 (1.9 to 82.6)	0.0 (0.0 to 0.1)
≥4000 g	6	100 (54.1 to 100.0)	100 (98.5 to 100.0)	100 (54.1 to 100.0)	100 (98.5 to 100.0)	100 (55.4 to 100.0)	32.5 (28.5 to 45.7)	0.7 (0.23 to 0.8)

cTvol-BPD = combined 3D-US of fractional thigh volume with biparietal diameter; LR+ = positive likelihood ratio; LR- = negative likelihood ratio; NPV = negative predictive value; PPV = positive predictive value

Table 6. Diagnostic accuracy of Hadlock's formula for birth weight estimation

Birth weight	n	Hadlock's formula						
		Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95% CI)	LR+ (95% CI)	LR- (95% CI)
<2,500 g	14	42.9 (21.8 to 66.0)	97.8 (95.0 to 99.3)	64.3 (35.1 to 87.2)	94.9 (91.3 to 97.4)	93.2 (91.1 to 97.4)	19.7 (7.27 to 53.47)	0.58 (0.40 to 0.85)
2,500 to 3,999 g	231	96.0 (92.6 to 98.2)	44.0 (24.4 to 65.1)	93.9 (90.0 to 96.6)	55.0 (31.5 to 76.9)	90.8 (87.1 to 93.6)	17.1 (1.2 to 2.4)	0.1 (0.0 to 0.2)
≥4,000 g	6	50.6 (6.8 to 93.2)	98.4 (95.9 to 99.6)	33.3 (4.3 to 77.7)	99.2 (97.1 to 99.9)	97.6 (95.1 to 98.2)	30.9 (7.8 to 122.8)	0.5 (0.12 to 1.4)

LR+ = positive likelihood ratio; LR- = negative likelihood ratio; NPV = negative predictive value; PPV = positive predictive value

after the ultrasound examinations) (r = 0.89)[14]. There were studies about addition of fractional Tvol to 2D-US formula and gave more accurate in birth weight estimation[15,16].

Yang et al analyzed Hong Kong Chinese women at 37 to 42 weeks of gestation and found an ICC of 0.95 from formula based on Tvol, FL, AC, and BPD, which provided higher accuracy than formulation based on 2D-US[15]. In the present study, the cTvol-BPD equation was more accurate than Hadlock's formula (ICC 0.8 versus 0.7).

The cTvol-BPD equation showed smaller mean difference, mean percentage error, mean absolute error, mean absolute percentage error than Hadlock's formula. This finding was similar to the studies of Khoury et al in pregnant women at 32 to 42 weeks of gestation[10], and Chang et al[14]. It could be suggested that 3D-US of fractional Tvol might be a key factor to find a reliable predicted fetal weight.

Considering the diagnostic accuracy of the new equation used in the group of birth weight 2,500 to 3,999 grams, the accuracy was high at 96.4%, compared to 90.8% when using Hadlock's formula. In low birth weight group, the numbers of case studied was small, only 14 cases. The accuracy in this low birth weight group was 96.4%. Since the sample was too small and the present study conducted in term pregnancy, using the new equation for prediction of low birth weight needs further validation studies.

Generally, the cut-off birth weight to define fetal macrosomia was between 4,000 to 4,500 grams, therefore, the author used the cut-off value of 4,000 grams. The cTvol-BPD equation offered the most accurate with the fetal macrosomia group (ICC 0.9), and Hadlock's formula offered the most reliable when the birth weight was between 2,500 and 3,999 grams (ICC 0.8) and less reliable when the birth weight was 4,000 grams or more (ICC 0.4). The cTvol-BPD equation showed the high sensitivity and specificity when used in fetal macrosomia. The numbers of fetal macrosomia was also too small.

The 3D-US has been widely used in many hospitals. Measurement of fractional Tvol could be performed in addition to routine 2D-US fetal parameter measurement. This new equation might be useful in prediction of fetal weight for planned delivery during late third trimester.

The limitation of the present study was small number of extremely high and low birth weight group. Caution should be exercised when using this formula for those extreme fetal weight.

To use this formula, general obstetrician need to practice 3D-US with experienced obstetric staff.

In conclusion, Tvol is highly correlated with actual birth weight. The cTvol-BPD equation was more accurate than 2D-US in birth weight estimation. Further validation studies are suggested in using this formula for estimation extreme fetal weight at 37 to 42 week of gestation.

What is already known on this topic?

The accuracy of fetal weight estimation is a key factor in management planning for reducing risks of both fetuses and mothers. The Hadlock's formula that is based on 2D-US parameters is widely used for birth weight estimation. However, it could overestimate in FGR and underestimate in fetal macrosomia. Fractional Tvol derived from 3D-US is a strongly correlated with actual birth weight. It gives a smaller percentage error and is more accurate when used for birth weight estimation.

What this study adds?

Fractional Tvol plays an important role to find the fetal weight, and combining it with 2D-US of BPD improves the precision of birth weight estimation, especially in fetus with abnormal growth.

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Potential conflicts of interest

The authors declare no conflict of interest.

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