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Fetal weight estimation in gestational diabetic pregnancies: comparison between conventional and three-dimensional fractional thigh volume methods using gestation-adjusted projection

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KEYWORDS: 3D ultrasound; accuracy; birth weight; estimated fetal weight; gestational diabetes; macrosomia

ABSTRACT

Objectives *To evaluate the accuracy of gestation-adjusted birth-weight estimation using a three-dimensional (3D) fractional thigh volume (TVol) method in pregnant women with gestational diabetes mellitus (GDM), and to compare it with the conventional two-dimensional method of Hadlock* et al.

Methods *Pregnant women with GDM were referred at 34 to 36 + 6 weeks' gestation for ultrasound examination. Estimated fetal weight (EFW) was obtained using both the Hadlock and the TVol methods. Using a gestation-adjusted projection method, predicted birth weight was compared to actual birth weight at delivery.*

Results *Based on 125 pregnancies, the TVol method with gestation-adjusted projection had a mean (± SD) percentage error in estimating birth weight of −0.01 ± 5.0 (95% CI, −0.96 to 0.98)% while the method of Hadlock with gestation-adjusted projection had an error of 1.28 ± 9.1 (95% CI, −0.33 to 2.87)%. The mean percentage error of the two methods was significantly different (*$P = 0.039$*), while the random error was not (*$P = 1.0$*). For the prediction of macrosomia (birth weight ≥ 4000 g, n = 19), sensitivity was 84 and 63% for the TVol and Hadlock methods, respectively (95% CI for difference −2 to 44%,* $P = 0.22$*) and specificity was 96 and 89% for the TVol and Hadlock methods, respectively (95% CI for difference 5–9%,* $P = 0.01$*).*

Conclusions *In women with GDM, a new method of estimating birth weight based on 3D-TVol measurements performed at 34 + 0 to 36 + 6 weeks' gestation and gestation-adjusted projection of estimated fetal weight, is more accurate than the standard method based on Hadlock's formula in predicting birth weight. The TVol method has comparable sensitivity but higher specificity than the Hadlock method in predicting neonatal macrosomia.* Copyright © 2013 ISUOG. Published by John Wiley & Sons Ltd.

INTRODUCTION

There is no international consensus on the definition of macrosomia, but the most common definition is birth weight ≥ 4000 g, which occurs in 0.5–15% of all pregnancies[1,2]. Macrosomia is associated with an increased risk for a number of perinatal complications including prolonged labor, shoulder dystocia with brachial palsy, facial nerve palsy, fractures of the clavicle and humerus, perinatal mortality and asphyxia[3–6].

Birth-weight estimation by two-dimensional (2D) ultrasonography is relatively accurate at predicting birth weight up to 3500 g, however all algorithms tend to underestimate the weight of large fetuses[7]. In 2010 Hart *et al.*[8] proposed a new specific formula for fetuses with a birth weight of ≥ 4000 g that showed a mean percentage error of −0.03 ± 4.6% in the prediction of birth weight. In the same year Hoopmann *et al.*[9] compared 36 different formulae to identify fetuses with a birth weight of ≥ 4000, ≥ 4300 and ≥ 4500 g. They observed the smallest mean percentage error for the Hart formula, but they also indicated that the detection rate decreased with increasing birth weight.

Evaluation of fetal soft tissues has been proposed in order to improve birth-weight prediction by ultrasound[10,11], and it has been shown that the precision of fetal weight estimation can be improved by adding fractional limb volume measurements to conventional 2D biometry[12].

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Gestational diabetes mellitus (GDM) is known to be an important risk factor for macrosomia[6]. Fetal fat mass levels, particularly in late gestation, are higher in fetuses of women with gestational diabetes than in those of healthy women[13].

The aim of our study was to evaluate the accuracy of birth-weight estimation using the three-dimensional (3D) fractional thigh volume (TVol) method in pregnant women with diabetes mellitus when performed at 34 + 0 to 36 + 6 weeks' gestation, and to compare the accuracy of birth-weight estimation by 3D-TVol with that of a conventional 2D approach using a gestation-adjusted projection method.

METHODS

This was a prospective, cross-sectional study performed between January 2007 and December 2010. During the study period, it was our policy to offer a 2-h 75-g oral glucose tolerance test to screen for GDM between 24 + 0 and 28 + 6 weeks' gestation. The diagnosis of GDM was made using the World Health Organization criteria[14]. Women with a singleton pregnancy complicated by GDM and followed up at our center were invited to have an ultrasound examination between 34 + 0 and 36 + 6 weeks' gestation to estimate fetal weight. The study was approved by the local ethics committee, and all women gave their informed consent.

Pregnancies were dated by measurement of crown–rump length in the first trimester, or by the date of a certain last menstrual period in women with regular cycles without antecedent oral contraceptive use, unless there was a discrepancy of more than 7 days between menstrual dating and sonographic assessment[15]. Women with multiple gestations, known fetal chromosomal abnormalities and/or congenital structural abnormalities were excluded from the study.

All ultrasound examinations were performed transabdominally by a single operator (N.P.) using an iU22 ultrasound machine with a V6-2 curved array volume transducer (Philips Healthcare, Bothell, WA, USA). A conventional transabdominal 2D scan was performed in order to obtain estimated fetal weight (EFW) using the Hadlock IV model, which incorporates biparietal diameter (BPD), head circumference, abdominal circumference (AC) and femoral diaphysis length (FL)[16].

3D volumes were acquired from the thigh as previously described by Lee *et al.*[17]. Image depth and magnification were adjusted for the volume of interest to fill at least two-thirds of the video display screen. The TVol was acquired from a sagittal sweep of the femoral diaphysis, with the acoustic focal zone adjusted near the long-bone diaphysis and the system gain optimized; soft tissues were included in the volume acquisition.

Patients were asked to remain still during the volume acquisition, which lasted approximately 10 s. At least two volumes for each patient were stored on a computer and later analyzed offline by one author (G.P.) using dedicated software (QLAB; Philips Healthcare). The single volume that was considered of better quality (no motion artifacts, sharpness of tissue boundaries) was chosen for analysis. The volume was opened in the multiplanar mode with the sagittal view displayed in Plane A, the axial view in Plane B and the coronal view in Plane C. On the sagittal plane FL was measured and each volume was subdivided into seven equidistant slices centered along the mid-thigh. Then the coronal plane was considered. Images were again magnified to fill at least two-thirds of the display. Soft-tissue borders were enhanced by the use of a color filter (sepia) with additional gamma curve adjustments for brightness and contrast. The area of the thigh for each of the seven slices was manually traced from a coronal view of the extremity including soft tissues. The fractional thigh volume was automatically calculated once all seven areas had been successfully measured. EFW was based on Model 6 by Lee *et al.*[12], incorporating BPD, AC and TVol.

Since fetal ultrasound biometry becomes less accurate nearer the time of delivery, possibly due to descent of the fetal head and reduction in amniotic fluid volume, we performed ultrasound scans 4–6 weeks before the estimated date of delivery[18,19].

Delivery data consisting of gestational age at birth, the infant's sex, birth weight and mode of delivery were obtained from the labor-ward database. Macrosomia was defined as birth weight ≥ 4000 g, while small for gestational age, appropriate for gestational age and large for gestational age were defined as birth weight below the 10th, between the 10th and 90th and above the 90th percentiles for gestational age, respectively[20].

Using the EFW at the time of the ultrasound scan obtained with the Hadlock and 3D-TVol methods, we constructed receiver–operating characteristics (ROC) curves to identify the optimal cut-off point for the prediction of macrosomia at birth.

Subsequently, the gestation-adjusted projection method was also used to predict birth weight using the EFW obtained with the Hadlock and 3D-TVol methods. This method assumes that the ratio between actual fetal weight and median weight for a given gestational age remains constant through the third trimester[21]. Predicted birth weights were compared with actual birth weight at delivery. For descriptive statistics mean and SD were used. The mean percentage error between predicted and actual birth weight, representing systematic error, was calculated for both methods as (estimated birth weight − actual birth weight) / actual birth weight. The 95% CIs for the mean percentage error were calculated as mean $\pm$ 1.96 $\times$ standard error, and were used to test for a significant difference between the TVol and Hadlock methods[9], in addition to applying the *t*-test for paired samples. The SD of the percentage error, representing random error, was compared between the two methods using the Pitman–Morgan test[22,23].

In order to visually assess any systematic bias in the two methods, and the relationship between any differences and the magnitude of the birth weight, differences between estimated birth weight and actual birth weight were plotted against actual birth weight on a scatter diagram[24].

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Table 1 Demographic and clinical details of the study population of 125 gestational diabetic pregnancies

Parameter	*Value*
Maternal age (years)	33.8 ± 4.7
Body mass index (kg/m^2)	26.6 ± 5.4
Pregnancy weight gain (kg)	13.1 ± 5.6
GA at diagnosis (weeks)	26+3 ± 4+1
Women on insulin therapy	66 (52.8)
GA at insulin therapy (weeks)	28.8 ± 5.1
GA at ultrasound (weeks)	35.8 ± 0.9
GA at delivery (weeks)	39.1 ± 1.2
Ultrasound to delivery interval (weeks)	3.3 ± 1.4
Birth weight (g)	3521 ± 536
Cesarean section	52 (41.6)
Normal vaginal delivery	60 (48.0)
Operative vaginal delivery	13 (10.4)
Male newborn	58 (46.4)

Data shown as mean ± SD or *n* (%). GA, gestational age.

Sensitivity, specificity and positive and negative likelihood ratios for the detection of macrosomia were calculated for both methods, and compared using McNemar's test for paired proportions. Confidence intervals for differences in sensitivity and specificity were also calculated[25]. All tests were performed with two-sided alternatives, and $P < 0.05$ was considered statistically significant. All calculations were performed using Stata SE 10.1 (Stata corporation, College Station, TX, USA).

RESULTS

One-hundred and twenty-five pregnancies were prospectively scanned between 34 + 0 and 36 + 6 weeks' gestation. Demographic and clinical data are shown in Table 1. Fifty-nine women (47.2%) were under diet control alone, the other 66 (52.8%) were on insulin therapy. Birth weight was classified as SGA in eight (6.4%) cases, AGA in 89 (71.2%) cases, LGA in 28 (22.4%) cases and macrosomia in 19 (15.2%) cases.

The mean (± SD) EFW at the time of ultrasound scan was 3064 ± 532 (95% CI, 3058–3070) g and 3014 ± 463 (95% CI, 2932–3096) g for the Hadlock and TVol methods, respectively. Optimal cut-off points for the prediction of fetal macrosomia without gestation-adjusted projection were 2980 g for the TVol method (area under the ROC curve (AUC), 0.66) and 3046 g for the Hadlock method (AUC, 0.63).

The TVol method with gestation-adjusted projection had a mean percentage error in estimating birth weight of −0.01 ± 5.0 (95% CI, −0.96 to 0.98)% while the Hadlock method with gestation-adjusted projection had an error of 1.28 ± 9.1 (95% CI, −0.33 to 2.87)%. The mean percentage errors of the two methods were significantly different ($P = 0.039$), while the random error was not ($P = 1.0$). The results of the two methods for the prediction of macrosomia in relation to the classification of actual birth weight are shown in Table 2. Sensitivity, specificity and positive and negative likelihood ratios are shown in Table 3. The McNemar test did not show any difference between the two methods in terms of sensitivity (95% CI for difference −2 to 44%, $P = 0.22$), while a significantly higher specificity was observed for TVol (95% CI for difference 5–9%, $P = 0.01$). For comparison, results of the two methods without gestation-adjusted projection are also provided.

Table 2 Accuracy of fractional thigh volume (TVol)-based and Hadlock-based methods from gestation-adjusted projection for the prediction of birth weight ≥ 4000 g in 125 gestational diabetic pregnancies

	Actual birth weight:	
Birth-weight projection	*≥ 4000 g*	*< 4000 g*
TVol method		
Predicted ≥ 4000 g	16	4
Predicted < 4000 g	3	102
Hadlock method		
Predicted ≥ 4000 g	12	12
Predicted < 4000 g	7	94

Data are given as *n*.

Figure 1a shows a plot of differences between estimated birth weights from gestation-adjusted projection and actual birth weights in relation to actual birth weights for the Hadlock method, and Figure 1b shows an equivalent plot for the TVol method. From the plots, it is immediately evident that the differences from actual birth weight for the TVol estimates are more narrowly distributed around zero than are those for the Hadlock estimates. The difference between predicted birth weight and actual birth weight has a negative slope with both methods, suggesting that the gestation-adjusted projection method tends to underestimate the birth weight of larger fetuses, and overestimate the birth weight of smaller fetuses.

DISCUSSION

In this study, we demonstrate that, in women with GDM, a new method of estimating birth weight based on 3D-TVol measurements performed at 34 + 0 to 36 + 6 weeks' gestation and gestation-adjusted projection of EFW, is more accurate than is a standard method based on Hadlock's formula in predicting actual birth weight. The TVol method with gestation-adjusted projection has comparable sensitivity but higher specificity than the Hadlock method with gestation-adjusted projection in predicting neonatal macrosomia; both methods perform better with gestation-adjusted projection than they do without gestation-adjusted projection, and using specific cut-off points calculated by ROC-curve analysis.

The incidence of macrosomia in our cohort of patients was 15%, consistent with the incidence reported in previous publications on gestational diabetic pregnancies: 15% according to Coustan and Imarah[26] and 9.5% in the HAPO study[27].

Ultrasound evaluation of fetal weight can be particularly important in diabetic patients since, although there are no clear, universally accepted guidelines, some authorities suggest that all fetuses of diabetic patients with

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Table 3 Sensitivity, specificity, positive (LR+) and negative (LR−) likelihood ratios of fractional thigh volume (TVol)-based and Hadlock-based methods with and without gestation-adjusted projection for the prediction of birth weight ≥ 4000 g

Method	*Sensitivity (95% CI)*	*Specificity (95% CI)*	*LR+ (95% CI)*	*LR− (95% CI)*
TVol with projection	0.84 (0.62–0.95)	0.96 (0.91–0.99)	22.32 (8.36–59.51)	0.16 (0.058–0.46)
Hadlock with projection	0.63 (0.41–0.81)	0.89 (0.81–0.93)	5.58 (2.96–10.52)	0.42 (0.23–0.75)
TVol without projection	0.90 (0.69–0.97)	0.61 (0.52–0.70)	2.31 (1.74–3.08)	0.17 (0.05–0.64)
Hadlock without projection	0.74 (0.51–0.88)	0.60 (0.51–0.69)	1.86 (1.30–2.66)	0.44 (0.20–0.94)

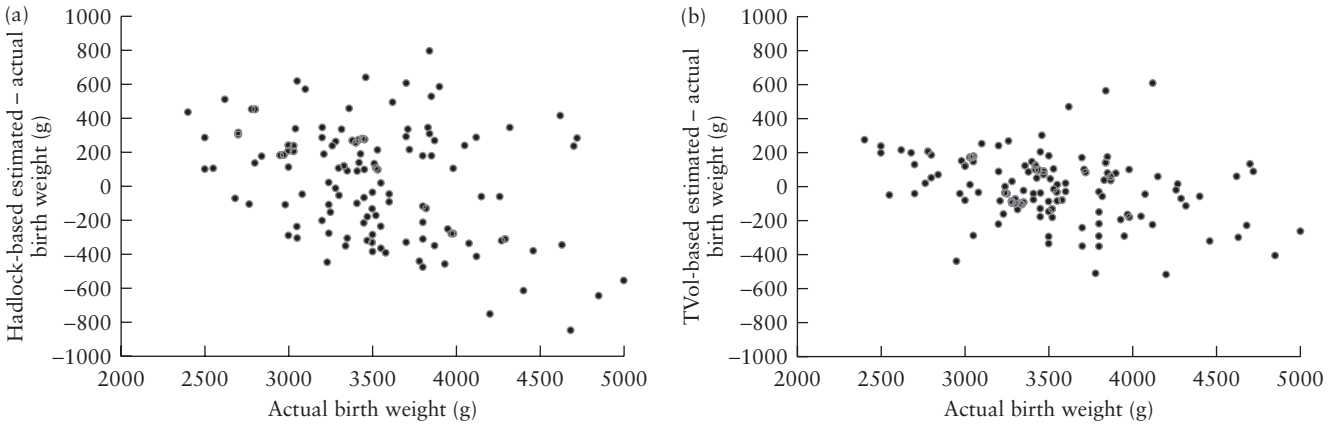

Figure 1 Scatter plots of differences between Hadlock-based (a) and fractional thigh volume (TVoL)-based (b) estimated birth weight from gestation-adjusted projection and actual birth weight, in relation to actual birth weight.

an EFW of ≥ 4000 g should be delivered by Cesarean section[3]. This can have important medicolegal implications and strengthens the importance of a correct fetal-weight estimation.

Ultrasound estimation of fetal weight has been reported using various formulae, but even in the best situation, the standard error reported is between 7 and 10%, and errors are reported to increase at the extremes of the fetal weight range[28]. Moreover in diabetic patients, fat distribution in the limbs can further compromise fetal-weight estimation by conventional formulae. To overcome this difficulty, cutaneous and subcutaneous soft tissue of the limbs has been evaluated using 2D ultrasound. However a new formula incorporating tissue thickness did not give significantly better results in predicting fetal weight[29].

In 1997 Chang *et al.*[30] analyzed 3D volumetry of the fetal thigh in predicting birth weight. They found that fetal-thigh evaluation was highly correlated with birth weight and had better mean values of percent error, absolute error and absolute percent error than did 2D formulae. The same group of authors also investigated the role of upper arm volumetry in predicting birth weight[31].

More recently, Lee *et al.*[17,32] introduced a new method of birth-weight prediction based on the fractional limb volume; in order to reduce the error caused by acoustic shadowing at the ends of the diaphysis they measured only 50% of the diaphyseal length. Prospective testing of this new model showed a better accuracy than did the Hadlock method[33]. Lee *et al.* measured all fetuses within 4 days of delivery. Fetuses near term can be difficult to measure accurately as the reduction in amniotic fluid and increased calcification of bones decrease resolution, while fetal head engagement low in the pelvis reduces the accuracy of cranial biometry[18,19]. A gestation-adjusted projection of EFW[21] has been suggested by Best and Pressman[34] in women with gestational and pregestational diabetes, showing an absolute percent error of 7.4 ± 6.3% for diabetic women and 8.3 ± 6.6% for non-diabetic women. This method has also been used in obese patients, and correctly excluded the presence of macrosomia with ≥ 90% specificity[35]. Our study is the first one reporting the use of the gestation-adjusted projection method together with fetal weight estimation using 3D fractional limb volume.

The present study has a number of limitations. Firstly, the number of macrosomic newborns is relatively small, allowing a rather imprecise estimate of the sensitivity and specificity of the method. Secondly, we used a gestation-adjusted method both with the TVol and Hadlock formulae; this did not allow us to compare our results with measurements taken nearer to delivery. Although there is evidence that gestation-adjusted methods have a better predictive power than do estimates obtained soon before delivery[34,35], we were unable to demonstrate the same in our population, as later ultrasound scans were not performed. Furthermore, the gestation-adjusted method is based on the assumption that the ratio of actual fetal weight to median weight at the same gestational age remains constant with increasing gestational age. This assumption has not been tested in pregnancies at risk of macrosomia, in which fetal growth may not necessarily maintain a stable relationship with the median. The negative slope observed in the scatter plots of differences (Figure 1) suggests that, in our population of women

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with GDM, the gestation-adjusted method may tend to underestimate fetal growth in larger fetuses.

In summary, although mode of delivery is not entirely dependent on fetal weight, the use of the TVol gestation-adjusted method at 34 + 0 to 36 + 6 weeks' gestation could give a better approach to the clinical evaluation of mode of delivery in diabetic pregnancies.

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