Predicting fetal weight by three-dimensional limb volume ultrasound (AVol/TVol) and abdominal circumference

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Abstract

Background: Fetal weight is an important parameter to ensure maternal and child safety. The purpose of this study was to use three-dimensional (3D) limb volume ultrasound combined with fetal abdominal circumference (AC) measurement to establish a model to predict fetal weight and evaluate its efficiency.

Methods: A total of 211 participants with single pregnancy (28–42 weeks) were selected between September 2017 and December 2018 in the Beijing Obstetrics and Gynecology Hospital of Capital Medical University. The upper arm (AVol)/thigh volume (TVol) of fetuses was measured by the 3D limb volume technique. Fetal AC was measured by two-dimensional ultrasound. Nine cases were excluded due to incomplete information or the interval between examination and delivery >7 days. The enrolled 202 participants were divided into a model group (134 cases, 70%) and a verification group (68 cases, 30%) by mechanical sampling method. The linear relationship between limb volume and fetal weight was evaluated using Pearson Chi-squared test. The prediction model formula was established by multivariate regression with data from the model group. Accuracy of the model formula was evaluated with verification group data and compared with traditional formulas (Hadlock, Lee2009, and INTERGROWTH-21st) by paired *t*-test and residual analysis. Receiver operating characteristic curves were generated to predict macrosomia.

Results: AC, AVol, and TVol were linearly related to fetal weight. Pearson correlation coefficient was 0.866, 0.862, and 0.910, respectively. The prediction model based on AVol/TVol and AC was established as follows: $Y = -481.965 + 12.194\text{TVol} + 15.358\text{AVol} + 67.998\text{AC}$, $R^2_{adj} = 0.868$. The scatter plot showed that when birth weight fluctuated by 5% (i.e., 95% to 105%), the difference between the predicted fetal weight by the model and the actual weight was small. A paired *t*-test showed that there was no significant difference between the predicted fetal weight and the actual birth weight ($t = -1.015$, $P = 0.314$). Moreover, the residual analysis showed that the model formula's prediction efficiency was better than the traditional formulas with a mean residual of 35,360.170. The combined model of AVol/TVol and AC was superior to the Lee2009 and INTERGROWTH-21st formulas in the diagnosis of macrosomia. Its predictive sensitivity and specificity were 87.5% and 91.7%, respectively.

Conclusion: Fetal weight prediction model established by semi-automatic 3D limb volume combined with AC is of high accuracy, sensitivity, and specificity. The prediction model formula shows higher predictive efficiency, especially for the diagnosis of macrosomia.

Trial Registration: ClinicalTrials.gov, NCT03002246; https://clinicaltrials.gov/ct2/show/NCT03002246?recrs=e&cond=fetal&draw=8&rank=67.

Keywords: Fetal weight prediction; Limb volume; Three-dimensional ultrasound

Introduction

Fetal weight prediction is an important part of obstetrics clinical work for maternal and child safety. Clinically, macrosomia (birth weight >4000 g) can cause many complications during pregnancy and after birth and can increase the risk of fetal shoulder dystocia and neonatal respiratory distress.[1] Macrosomia also increased the risk of cesarean section, postpartum bleeding, and vaginal tearing. At present, the existing weight evaluation formulas generate a large overall evaluation error.

Since the 1980s, many formulas have been used to evaluate fetal weight. Traditionally, four ultrasound measurements have been used to estimate the fetal weight (EFW), namely, biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL). All of these measurements are made using two-dimensional (2D) ultrasound, and there are many formulas for calculating EFW using different combinations of these indicators.[2] The Hadlock formula is commonly used in current practice to calculate fetal EFW. According to Chauhan *et al*[3] the accuracy of different techniques varies

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greatly (19%–87%), they summarized 51 papers on fetal weight assessment with an overall accuracy of 62% (the difference between EFW and birth weight was considered to be relatively accurate when birth weight fluctuated by 10% [i.e., 90% to 110%]). Stirnemann *et al*[4] proposed the formula of INTERGROWTH-21st based on 2D measurement parameters in 2017, and this method is still in the testing stage. Based on the traditional ultrasound measurements, medical researchers are also looking for other parameters related to fetal weight as markers for the fetus. Lee *et al*[5] studied the measurements of fetal fractional limb volume, including the entire thigh, fat content, muscle volume, and bone density, which can be used to evaluate the nutritional status of the fetus. Whether this biological measurement differs by race or whether it applies to Chinese populations is unknown.[6] The purpose of this study was to use semi-automatic three-dimensional (3D) ultrasonic measurement of limb volume, combined with fetal AC to establish a model to predict fetal weight and evaluate its efficiency in predicting fetal weight before delivery.

Methods

Ethical approval

The study was a part of an international multi-center program named Automated Fetal Weight Estimation: a multi-center validation using fractional limb volume. This study was approved by the Institutional Review Board for Baylor College of Medicine and Affiliated Hospitals (No. H-39343) and the Medical Ethics Committee of Beijing Obstetrics and Gynecology Hospital, Capital Medical University (No. 2017-KY-009-01). This study followed the ethical standards for research using human subjects established in the *Declaration of Helsinki*.

Informed consent was obtained from all patients, and participants were registered according to the protocol approved by the Department of Ultrasound, Beijing Obstetrics and Gynecology Hospital, Capital Medical University. This study required that the interval between examination time and delivery time was to be <7 days.

Subjects

According to the study protocol, we enrolled a total of 211 Chinese single pregnant women (age >18 years) at 28 to 42 weeks of gestation between September 2017 and December 2018, with a prenatal body mass index <35.0 kg/m^2. Gestational weeks were calculated from the first day of the woman's last normal menstrual period and were determined in the first trimester of pregnancy based on measurements of crown rump length.[7,8] We excluded fetuses with structural or chromosomal abnormalities. Nine of 211 cases were eventually excluded from the data analysis because of the following reasons: (1) Time interval between ultrasound examination and delivery was >7 days; (2) Fetus was delivered in another hospital and the information was incomplete. All subjects were divided into two groups according to the mechanical sampling method. Model group (70%; $n = 134$) was used to establish the model formula, and verification group (30%; $n = 68$) was used to compare the predictive accuracy of the model and traditional formulas (Hadlock, Lee2009, and INTERGROWTH-21st). The proportion of macrosomia in the two groups (14.2% *vs*. 11.8%) was similar.

Measurements

Images were collected by a Samsung WS80A high-grade color Doppler ultrasound diagnostic instrument (Samsung Medison Co., Seoul, Korea). Both 2D and 3D ultrasound examinations were performed by one sonographer with >10 years of experience. The sonographer was required to measure 30 arm volume (AVol) and 30 thigh volume (TVol) training cases using the semi-automated 3D analysis package on the ultrasound system. The operator received remote review training and datasets from standardized research procedures before the acquisition and analysis of automated fetal limb volume measurements.

Data acquisition

Data were collected through case summaries of pregnant women and newborns. Maternal data such as height, weight, age, the number of pregnancies, birth record, past medical history, and the occurrence of obstetric complications (gestational hypertension, gestational diabetes mellitus [GDM]) were collected. All the complications were diagnosed by the obstetrician in the following criteria. Gestational hypertension: systolic blood pressure >140 mmHg (1 mmHg = 0.133 kPa) or diastolic blood pressure >90 mmHg after 20 weeks of gestation, without proteinuria.[9] GDM: fasting plasma glucose ≥5.1 mmol/L, or have a 75-g oral glucose tolerance test, after 1 h ≥10.0 mmol/L or after 2 h ≥8.5 mmol/L.[10] Neonatal data, such as birth weeks, sex, delivery style, body length, and HC, were collected. The newborn's birth weight was measured on a standard calibrated weighing scale. All measurement information was completed by one doctor.

BPD, HC, AC, FL, and humerus length were acquired by 2D trans-abdominal probe.[11] The ultrasound volume data of the fetus's upper arm and thigh were obtained by 3D convex array probe, and limb data (taken twice) were averaged later. Key steps for volume data analysis using semi-automatic 5D volume software (5D Limb Vol) are summarized below: (1) Activate 5D Limb Volume key; (2) Detect the length of long bones using software, choose Volume type (AVol or TVol), use "Auto" button to quickly trace the cross-section of the middle thigh or middle arm of the fetus, and press the "Assign" button to display the resulting data; (3) The measurements can be measured manually.

Statistical analysis

The collected data were analyzed using SPSS 23 (IBM Corp., Armonk, NY, USA). Quantitative data was presented as the mean and standard deviation, while qualitative data was presented as frequency and percentage. Kolmogorov-Smirnov test was used to test the normality of the data. The receiver operating characteristic (ROC) curve was used to analyze the value of limb volume and AC in predicting macrosomia. The cases were sorted according to the collection time and then rearranged the numbering order according to the mechanical sampling

method of 1, 1, 2 based on the original sorting. The last sample "2" was designated as the verification group. The model group accounted for 70% and the verification group accounted for 30% in overall cases. In the model group, Pearson chi-squared test was used to show the relationship between measured data and fetal weight, and multiple linear regression analysis was used to obtain the prediction model formula containing 2D ultrasonic measurement and 3D partial limb volume measurement parameters. Overlapping scatter plots were used to compare the predicted results of the traditional formula and multivariate linear model with the actual fetal weight and its 5% interval. The difference between the predicted weight of AVol/TVol and AC combined model and Hadlock formula, Lee2009, and INTERGROWTH-21st formula was verified by the case-matched *t*-test and mean residual analysis in the verification group.[12] $P < 0.05$ was considered statistically significant.

Results

Basic information

According to the mechanical sampling method, all the delivery fetuses were divided into the model group (134 cases, 70%) and the verification group (68 cases, 30%). The proportion of macrosomia in the two groups (14.2% *vs*. 11.8%) was basically similar. The interval between examination and delivery was −1.6 to 1.6 days. The parameters of the fetuses were measured by 2D and 3D ultrasound before delivery as shown in Table 1. Fractional limb volume was measured by 3D ultrasound [Figure 1].

Table 1: Descriptive data for the model and verification groups.

Variables	Model group ($n = 134$)	Verification group ($n = 68$)
Maternal		
Age (years)	32.0 ± 4.3	31.6 ± 4.2
BMI (kg/m^2)	22.5 ± 3.4	21.7 ± 3.0
Mode of delivery		
Vaginal	78 (58.2)	43 (63.2)
Cesarean section	56 (41.8)	25 (36.8)
Gestational diabetes		
Yes	28 (20.9)	6 (8.8)
No	106 (79.1)	62 (91.2)
Fetal		
AC (cm)	34.7 ± 2.3	34.8 ± 2.2
TVol (cm^3)	87.4 ± 20.0	87.6 ± 17.9
AVol (cm^3)	37.1 ± 8.6	37.0 ± 7.5
Gender		
Male	67 (50.0)	33 (48.5)
Female	67 (50.0)	35 (51.5)
Macrosomia		
Yes	19 (14.2)	8 (11.8)
No	115 (85.8)	60 (88.2)
Neonatal birth weight (g)	3513 ± 542	3496 ± 502

Data were presented as mean ± standard deviation or *n* (%). AC: Abdominal circumference; AVol: Arm volume; BMI: Body mass index; TVol: Thigh volume.

Predictive value for macrosomia

ROC curve was used to analyze the value of limb volume and AC in predicting macrosomia. The area under the curve (AUC) of TVol and AVol was 0.923 and 0.911, respectively, and that of AC was 0.862. The sensitivity and specificity of TVol were 81.5% and 87.4%, respectively, when the cut-off value was 100.95 cm^3. When the cut-off value of AVol was 40.13 cm^3, the sensitivity was 100% and the specificity was 76%. When the cut-off value of AC was 36.25 cm, the sensitivity was 70.4% and the specificity was 85.1% [Figure 2A].

Establish and verification of prediction models

AC, AVol, and TVol were linearly related to fetal weight by Pearson Chi-squared test. Correlation coefficient of AC, AVol, and TVol were 0.866, 0.862, and 0.910, respectively ($P < 0.001$). Multiple linear regression model formula was established by the data from model group, the formula was: $Y = -481.965 + 12.194\text{TVol} + 15.358\text{AVol} + 67.998\text{AC}$, $R^2_{adj} = 0.868$ ($F = 292.423$, $P < 0.001$). The multivariate linear model covered 86.8% of the factors that determined fetal weight, and the formula was statistically significant.

Weight predicted by the following formulas and the model formula were compared with the actual fetal weight in verification group. (1) Hadlock2: Log_{10} (weight) = 1.335 − 0.0034 × AC × FL + 0.0316 × BPD + 0.0457 × AC + 0.1623 × FL; (2) Hadlock3: Log_{10} (weight) = 1.326 − 0.00326 × AC × FL + 0.0107 × HC + 0.0438 × AC + 0.158 × FL; (3) Hadlock4: Log_{10} (weight) = 1.3596 − 0.00386 × AC × FL + 0.0064 × HC + 0.00061 × BPD × AC + 0.0424 × AC- + 0.174 × FL; (4) Lee2009 (TVol): Ln Birth Weight = −0.8297 + (4.0344 × Ln BPD) − (0.7820 × (Ln BPD)^2) + (0.7853 × Ln AC) + (0.0528 × [Ln TVol]^2); (5) Lee2009 (AVol): Ln birth weight = 0.5046 + 1.9665 (Ln BPD) − 0.3040 (Ln BPD)^2 + 0.9675 (Ln AC) + 0.3557 (Ln AVol); and (6) INTERGROWTH-21st (HC, AC): Log (EFW) = 5.084820 − 54.06633 (AC/100)^3 − 95.80076 (AC/100)^3 × log (AC/100) + 3.136370 × (HC/100). When we used model formula within a deviation of 5% of actual weight, the scatter plot showed that there is a little difference between the predicted and the actual birth weight [Figure 2B-2H].

The predicted weight by model formula showed no significant difference with the actual birth weight ($P = 0.314$, $t = -1.015$), and subgroup analysis for macrosomia showed the same consistency ($P = 0.146$, $t = 1.636$). Compared with traditional formulas, the overall prediction efficacy of the model formula was slightly better than the Hadlock4/2, Lee2009, and INTERGROWTH-21st formulas. Moreover, the model formula was slightly better than Lee2009 and INTERGROWTH-21st formulas in predicting the weights of macrosomia [Table 2].

We compared the mean residuals of all verified samples (degrees of freedom = 64) and found that the overall prediction effect of the established linear model was better than other formulas. We also compared the

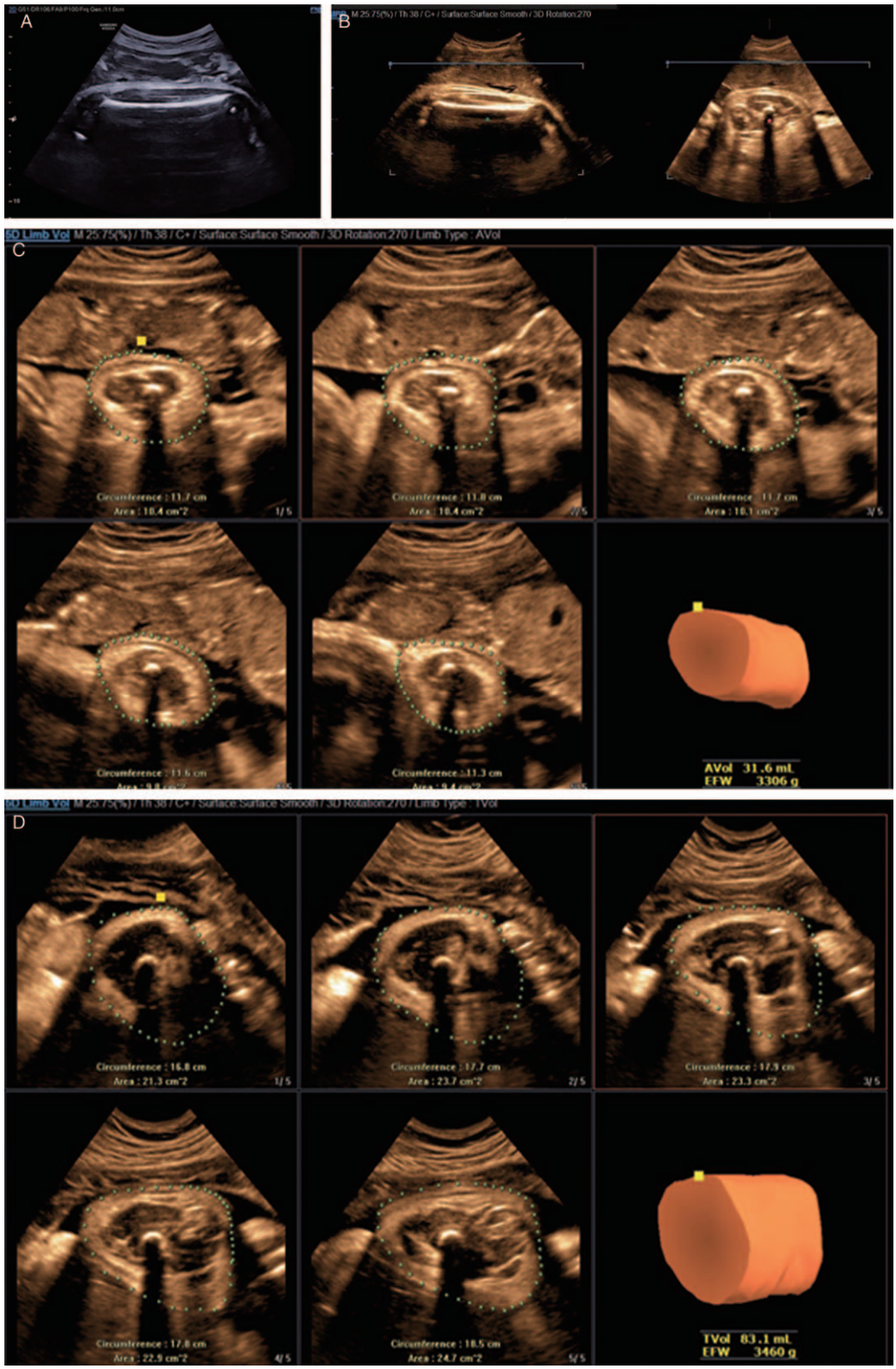

Figure 1: Fractional AVol and TVol measurements by 3D ultrasound. (A) Obtain images of fetal limbs; (B) Activate 5D volumetric measurement kit; (C) Measurement of fractional AVol by 3D ultrasound; (D) Measurement of fractional TVol by 3D ultrasound. AVol: Arm volume; TVol: Thigh volume.

mean residuals of verified macrosomia samples (degrees of freedom = 4) and found that the prediction effect of the established linear model was better than the Lee2009 and INTERGROWTH-21st formulas, with the mean residual of 35,360.170 [Table 3]. The AUC of the model for macrosomia birth weight prediction was 0.958, its sensitivity and specificity were 87.5% and 91.7%, respectively [Figure 2I and Table 4].

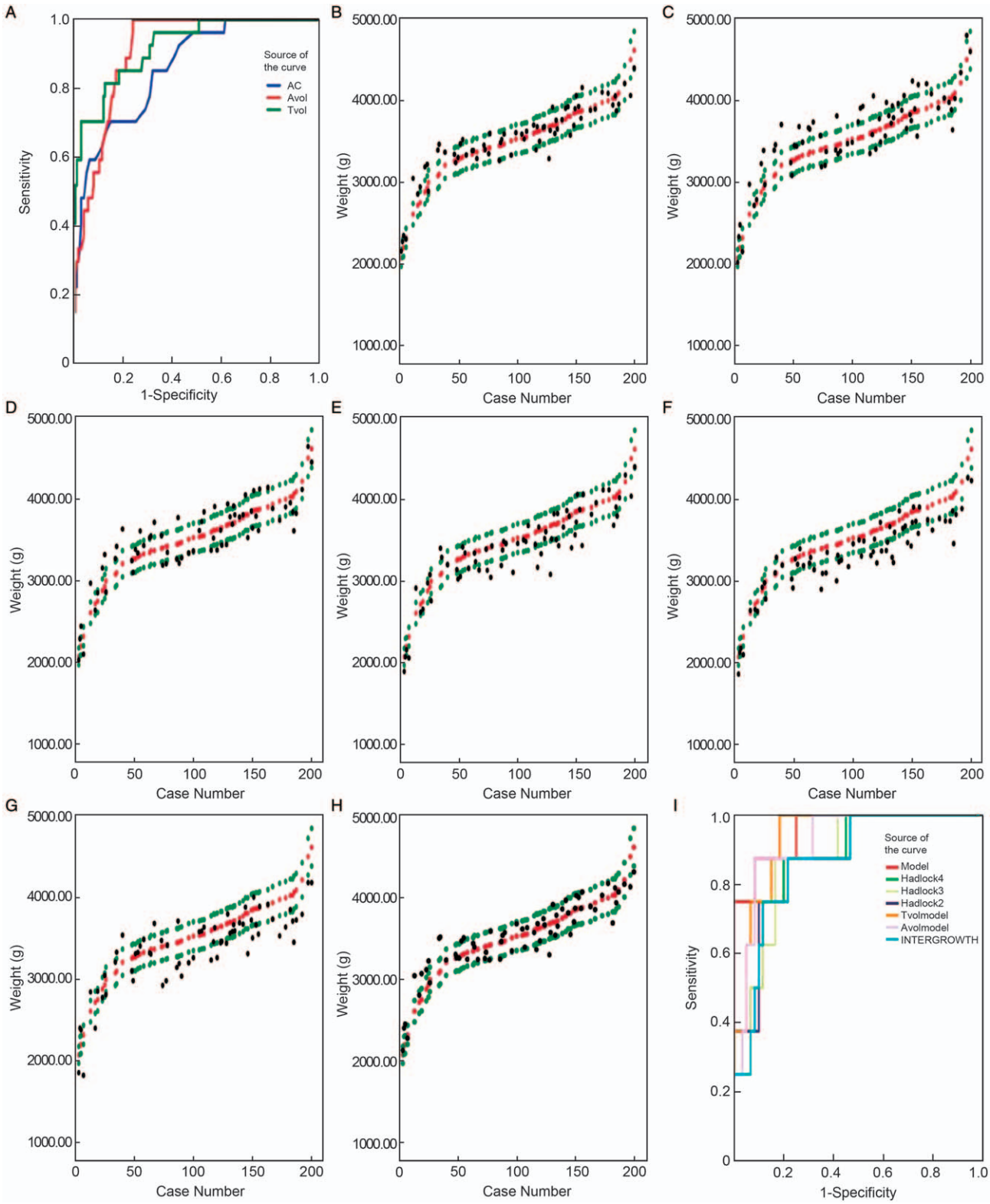

Figure 2: (A) The predictive value of TVol, AVol, and AC for macrosomia by ROC curve. (B) Hadlock4; (C) Hadlock3; (D) Hadlock4; (E) Lee2009 (TVol); (F) Lee2009 (AVol); (G) INTERGROWTH-21st; (H) Model established by this study with the actual fetal weight. Red dots: The actual fetal weight; Black dots: The predicted fetal weight; Green dots: The actual fetal weight with a 5% deviation. (I) The predictive value of the model and traditional formulas for macrosomia. AC: Abdominal circumference; AVol: Arm volume; ROC: Receiver operating characteristic; TVol: Thigh volume.

Discussion

Fetal weight prediction is an important part of prenatal management. It provides the best diagnostic information for prenatal care services, although there are many clinical methods and magnetic resonance technology used in the prediction and assessment of fetal weight.[13-15]

There may be many factors affecting weight assessment before labor. For example, due to the drop of fetal head position, the measurement of BPD/HC may be inaccurate, and due to the influence of amniotic fluid volume and uterine contraction, some fetal tissues may be deformed. Therefore, ultrasonic examination and the selection of measurement variables will also affect the accuracy of the assessment.

Nearly 75% of body fat is found in subcutaneous tissues. Fetal femoral and humerus tissue thickness are sensitive indicators of fetal development and nutritional status. As early as 1987, Vintzileos *et al*[16] demonstrated that the addition of thigh circumference in measurements of head, abdomen, and FL could improve the accuracy of fetal weight estimates. Ultrasound measurement of fetal visceral adipose tissue and subcutaneous fat thickness has been assessed as a method for predicting fetal weight.[17] Abuelghar *et al*[18] showed that the fetal mid-thigh soft tissue thickness is a simple, practical, and easy-to-apply fetal weight estimation parameter. Because of irregular tissue morphology, it is difficult to measure this accurately in 2D imaging. The application of 3D ultrasound can provide more accurate volume of information.[19] Khoury *et al*[20] found that the correlation between fetal TVol and neonatal fat mass was closer than Mack *et al*'s[21] finding, the latter showed that ultrasound measurement of partial limb volume could reflect the nutritional status of the intrauterine fetus through the 3D ultrasound examination. Combined with the formula obtained using 2D ultrasound measurement parameters, it also improved the accuracy of weight prediction of fetuses in the third trimester. Simcox *et al*'s [22] study of fetuses between 34 and 36 weeks found a better correlation between 3D partial limb volume and fetal weight. Abdel and Kattan[23] analyzed the normal development of Egyptian fetuses between 20 and 41 weeks to obtain the reference value of fetal TVol.

Our research was a prospective study. Among the included data, the measurement data of TVol was 87.5 ± 19.3 cm^3, and AVol was 37.0 ± 8.2 cm^3 at 29^{+2} to 42 weeks of gestation. Pearson analysis results of the model group showed that TVol, AVol, and AC were linearly correlated with actual fetal birth weight. The multivariate linear prediction model with AC and fetal partial limb volume is simple and easy to understand. The prediction formula is $Y = -481.965 + 12.194\text{TVol} + 15.358\text{AVol} + 67.998\text{AC}$ ($R^2_{\text{adj}} = 0.868$). In the model, when TVol, AVol, and AC increase by one unit, the weight gain is predicted to be 12.194 g, 15.358 g, and 67.998 g, respectively. Overlapping scatter plot was used to compare the predicted results of traditional formula and multivariate linear model formula with the actual fetal weight and its 5% interval. The results show that the predicted weight value of the multivariate linear model is closer to the actual birth weight of the fetus. The predicted weight by model and Hadlock3 formulas is not significantly different from the

Table 2: Comparison of predicted weight by different formulas and actual birth weight by paired *t*-test.

Formula	Predicted fetal weight (g)	Verified samples ($n = 68$)		Macrosomia in verified samples ($n = 8$)	
		t value	*P* value	*t* value	*P* value
Model	3518 ± 446	−1.015	0.314	1.636	0.146
Hadlock4	3553 ± 503	−2.221	0.030	1.182	0.276
Hadlock3	3514 ± 487	−0.716	0.477	2.474	0.043
Hadlock2	3589 ± 512	−3.571	0.001	0.401	0.701
Lee2009 (TVol)	3403 ± 510	3.981	<0.0001	2.227	0.061
Lee2009 (AVol)	3318 ± 469	8.959	<0.0001	6.885	<0.0001
INTERGROWTH-21st	3371 ± 467	4.468	<0.0001	8.545	<0.0001

AVol: Arm volume; TVol: Thigh volume.

Table 3: Residuals and mean residuals in verified samples.

Formula	Verified samples ($n = 68$)		Macrosomia in verified samples ($n = 8$)	
	Residual	Mean residual	Residual	Mean residual
Model	2,227,691.00	35,360.17	401,709.00	133,903.00
Hadlock4	3,257,170.00	51,701.11	349,458.00	116,486.00
Hadlock3	3,003,647.00	47,676.94	381,379.00	127,126.33
Hadlock2	3,689,510.00	58,563.65	307,701.00	102,567.00
Lee2009 (TVol)	3,072,896.00	48,776.13	489,538.75	163,179.58
Lee2009 (AVol)	3,931,483.50	62,404.50	934,315.50	311,438.50
INTERGROWTH-21st	4,563,010.80	72,428.74	1,231,069.55	410,356.52

AVol: Arm volume; TVol: Thigh volume.

Table 4: Predictive value of model and traditional formulas for macrosomia by receiver operating characteristics (ROC) curve.

Formula	AUC	Sensitivity	Specificity
Model	0.958	0.875	0.917
Hadlock4	0.881	0.875	0.800
Hadlock3	0.879	0.875	0.833
Hadlock2	0.877	0.875	0.783
Lee2009 (TVol)	0.938	1.000	0.800
Lee2009 (AVol)	0.923	0.875	0.917
INTERGROWTH-21st	0.869	0.875	0.783

AVol: Arm volume; AUC: Area under the curve; TVol: Thigh volume.

actual birth weight, with *P* values of 0.314 and 0.477, respectively. The mean residual calculation indicates that the mean residual of the model formula was the smallest, that is, the deviation from the actual birth weight was the smallest. The overall prediction effect of the model formula was better.

Maruotti *et al*[24] used ultrasound to measure the soft tissue of the abdomen or thigh to predict the macrosomia of the fetus >34 weeks of gestation. The results showed that the sensitivity and specificity were 80% and 95%, respectively, and the AUC of fetal soft tissue for diagnosis of macrosomia was 0.920. Therefore, fetal soft tissue measurement is accurate in predicting macrosomia. Youssef *et al*[25] used ultrasound to measure the diameter of the fetal acromion and combined this measurement with fetal AC to predict macrosomia and shoulder dyspraxia. The sensitivity was 96.4% and the positive predictive value was 88.4% when the cut-off value of the acromion was 15.4 cm. The study also showed that when the cut-off value of AC was 35.5 cm, the sensitivity was 96.4% and the positive predictive value was 87.7%. Gibson *et al*[26] focused on fetal populations with suspected macrosomia and found that TVol can provide the best estimate for the percentage of body fat and birth weight of newborns. Pagani *et al*[27] measured the fetal weight from 34 to 36^{+6} weeks of gestation in diabetic pregnant women. The results showed that TVol had considerable sensitivity and specificity. The weight prediction efficacy was improved after Lee *et al*[28] applied partial limb volume plus 2D measurement parameters in diabetic pregnant women.

In our study, the incidence of macrosomia in the model group and the verification group was 14.2% and 11.8%, respectively. In all the 202 cases, the AUC for predicting macrosomia with TVol and AVol was 0.923 and 0.911, respectively, and that of AC was 0.862. The sensitivity and specificity of TVol for predicting macrosomia were 81.5% and 87.4%, respectively, when the cut-off value was 100.95 cm^3. When the cut-off value of AVol was 40.13 cm^3, the sensitivity was 100% and the specificity was 76%. When the cut-off value of AC was 36.25 cm, the sensitivity was 70.4% and the specificity was 85.1%. The results show that TVol, AVol, and AC had statistical value in predicting fetuses with weight >4000 g, and the sensitivity and specificity of fractional limb volume were both higher than those of AC. After establishing the model formula, the analysis of macrosomia in the verification group showed that the predictive value of the model formula was better than the Lee2009 and INTERGROWTH-21st formulas. The prediction sensitivity was 87.5% and the specificity was 91.7%. However, compared with the traditional formulas, the specificity of the limb volume model was higher, but the sensitivity showed no obvious improvement. This result may be related to the small number of macrosomia cases in this study, and the proportion of gestational diabetes in the validation group was also different from that in the model group. Abele *et al*[29] found that accuracy of fetal weight prediction may be influenced by the number of measured parameters; the more parameters are contained in the formula, the higher of the accuracy. Our study showed that the predicted results differ greatly from the actual weight, the average percentage error predicted was −2% to −5% by Hadlock formula, −4% by Lee2009 (TVol), and −8% by Lee2009 (AVol). These systematic errors suggest that the predicted weight of macrosomia was lower than the actual birth weight, which was also consistent with the results of Aviram *et al*.[30]

Fetal growth is related to several factors: genetic factors, maternal factors (such as nutritional age pregnancy complications and diseases), lifestyle (including smoking and drug use), and socioeconomic factors. Many factors affect the accuracy of the assessment, including the abnormal fetus, large deviation in data collection of AC and HC, and difficulty in obtaining accurate measurement section due to examination conditions in late pregnancy. Plonka *et al*[31] showed that fetuses with different conditions should be assessed with different formulas. Dimassi *et al*[32] showed that ultrasound examination in the delivery room was reasonable, but the accuracy rate of EFW was only 62.1%. The model established in this study did not include fetal head measurement variables, which avoided the influence of standard measurement section acquisition factors. Chang *et al*[33] used fetal TVol to predict fetal birth weight in Taiwan (China) in the 1990s, which showed several advantages. However, due to the time-consuming multiplanar model (10–15 min) and the influence of femur sound shadow at limb edge, its application is limited. The semi-automatic technology used in this study has an operation time for 3D inspection of about 2 min.[34] The dependence on the inspection operator is different from the traditional inspection method. Machine for limb volume measurement provided semi-automatic adjustment, as well as a manual mode to measure limb volume, which was faster than manual mode alone. Especially in large populations as are present in China, the semi-automatic technique can save inspection time and improve work efficiency while maintaining repeatability.[35]

Our study had several limitations. In the experimental design stage, we excluded maternal obesity, twin pregnancy, and other factors, but in clinical practice, various such cases may occur, so the established prediction model needs to be extended to a larger population to determine its significance. It is also necessary to assess the model according to fetal weight classes (eg, <2500 g; 2500–4000 g; >4000 g) to improve the evaluation of performances.

In the last ultrasound examination before labor, this model can accurately predict the fetal weight based on semi-automatic 3D ultrasound limb volume technology combined with the fetal AC. Compared with the traditional method, it shows higher prediction efficiency, especially for the diagnosis of macrosomia, and the sensitivity and specificity of fetal limb volume measurement were better than AC measurement by 2D ultrasound. In future research, we expect to further apply and verify the linear model in the population suspected of macrosomia and identity broader prospects in the clinical application that may be useful in clinical decision-making.

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Conflicts of interest

None.

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