

Establish a new equation for ultrasonographic estimated fetal weight in Chongqing: a prospective study

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Abstract

Background: Variation in fetal growth between populations should not be ignored, and a single universal standard is not appropriate for everyone. Therefore, according to regional population characteristics, it is necessary to find a more accurate equation for ultrasound estimation of fetal weight. The purpose of this study was to create a new equation for ultrasound estimation of fetal weight according to the local population in Chongqing and compare it with representative equations.

Methods: This prospective study included data on pregnant women who gave birth to a single child at full term in our hospital from December 2016 to November 2019. The fetal weight compensation model was established by using the second-order linear regression model, then the equation of fetal weight was established by utilizing the multiple reverse elimination regression technique. The accuracy of the equation established in this study was respectively compared with the Hadlock equation, Combs equation and Stirnemann equation by estimation error.

Results: Through the fetal weight compensation equation, the predicted fetal weight equation suitable for Chongqing fetuses was successfully established with the variables of biparietal diameter, head circumference, abdominal circumference and femur length. In the sets established by 1925 data, the mean absolute error and standard deviation of the estimation error of the equation established in this study were 178.9g and 140.3g respectively. In the 300 validation sets, the mean absolute error and Standard deviation of Chongqing equation were 173.08g and 128.59g respectively. Compared with representative equations, the mean absolute error and the standard deviation of the new equation were the lowest.

Conclusions: According to the local population characteristics of Chongqing, this study created the equation for estimated fetal weight, which is more accurate and suitable. This equation has high clinical guidance and reference value for monitoring and management of fetal weight and maternal delivery process.

Background

Estimated fetal weight (EFW) is part of the important contents of antenatal care, and fetal weight is a key factor influencing the timing, manner and perinatal outcome of fetal delivery[1–2]. With the development of ultrasound technology, Ultrasound estimation of fetal weight before birth had become one of the principal means for modern obstetrics to assess fetal weight, the identification and management of high-risk pregnancies[3–4]. In order to get a good perinatal outcome, fetal weight can be dynamically monitored by ultrasound. Ultrasound estimation of fetal weight before birth can assess fetal growth and development, guide both the timing and mode of delivery of a pregnancy, respond to possible problems during delivery in a timely and effective manner. Based on fetal biological parameters measured by ultrasound, scholars at home and abroad derived several regression equations for EFW by multiple linear regression method[5–9].

Most hospitals in China are currently used the Hadlock equation established in 1985 based on US fetal database[5], probably because ultrasonic diagnostic instruments mostly default to this equation. Due to the regional environment, racial differences[10], genetics, dietary[11] and many other factors[12], the trunk ratio and fat content of fetuses in different regions may vary. Variation in fetal growth between populations should not be ignored. There may be some error in directly using Hadlock equation to estimate fetal weight in Chinese fetuses. In recent years, the ultrasonographic equation suitable for Chinese Han population was also being explored in China to predict fetal weight[13–14]. Therefore, in order to improve the accuracy of estimating fetal weight in the local population, it is necessary to find a new and more accurate regression equation to estimate fetal weight according to the population characteristics of different regions.

The aim of this study was to establish the ultrasonographic estimation equation of fetal weight based on fetal growth parameters of Chongqing pregnant women, as well as to respectively compare this equation with Hadlock equation[5], Combs equation[6] and Stirnemann equation[7] to ensure the accuracy of the new equation.

Methods

This prospective study included the data of pregnant women who gave birth to a single child at full term in our hospital from December 2016 to November 2019. This study recruited women with gestational age from 37 to 41 + 6 weeks. All had a single gestation and neonates were born with normal outcomes. All ultrasound examinations were performed using GE Voluson E8 and GE Voluson E10 machines (General Electric Healthcare, U.S.A). The birth weight of all fetuses was weighted by electronic baby scale DY-1 (Shanghai Guangzheng Medical Instrument Co., LTD). All the sonographers participating in the study received specific training and their measurement techniques were subjected to rigorous quality assurance[15–16].

The inclusion criteria were as follows: Pregnant women in various districts and countries in Chongqing. Women had a definite gestational week (the definite last menstrual period was consistent with the gestational week corresponding to length of the head and hip measured by ultrasound); Ultrasound examination was performed within 7 days before delivery; There was no limit to the number of pregnancies.

The exclusion criteria were as follows: those with structural fetal anomaly detected on ultrasound or confirmed aneuploidy; there had complications during pregnancy (including gestational diabetes, gestational hypertension, fetal growth restriction and so on).

General information included maternal demographic data(ethnicity and age), last menstrual period, complications of the pregnant woman, gestational week at termination of pregnancy, data of birth, ultrasonic examination dates, and birth weight of newborn (The newborns were put on an electronic scale after the delivery by senior nurse working in the delivery room.) .

Fetal ultrasound parameters included biparietal diameter(BPD), head circumference(HC), abdominal circumference(AC), femur length(FL), all of which were measured by the last prenatal ultrasound.

The measurement methods were as follows[17]: all the measurements should fill at least 30% of the monitor screen; fetal growth parameters were measured three times and the mean values were taken. Fetal BPD and HC measurements were taken in an axial view at the level of the thalami, with an angle of insonation as close as possible to 90 degrees. The cerebellum was not included in the section. The head had to be oval in shape, symmetrical, centrally positioned; linear distance from the outer edge of the proximal to the outer edge of the distal skull. Fetal HC containing no extra cranial soft tissue along the outer edge of the fetal skull was directly measured using the elliptical function key.

Fetal AC measurements were taken in a cross-section view of the fetal abdomen as close as possible to circular, showing the stomach, ventral umbilical vein segment, left and right branches of the portal vein and spinal. The kidneys and bladder had not to be visible. For the measurements, the contour of the ellipse was placed on the outer border of the abdomen.

Fetal FL measurements required a standard section that showed the full length of the femur clearly and the angle between the femoral long axis and sound beam had to be greater than 60 degrees. The intersection of the callipers was placed on the outer borders of the edges of the femoral diaphysis (outer to outer) ensuring clear femoral edges; ultrasound artefacts of the femoral edges such as the proximal trochanter or pointed femoral spurs were not included in the measurement.

Statistical analysis

In order to make the ultrasonic measurement corresponds to the fetal weight at the time of ultrasonic measurement, the weight compensation equation was established. With gestational age as the independent variable and birth weight as the dependent variable, the second order linear regression model was used to establish the weight compensation equation with time to compensate the difference between the weight and the birth weight at the time of ultrasonic measurement. The fetal weight prediction model was established by reverse elimination regression after the weight difference was compensated[18].

All measured values (BPD/HC/AC/FL) were included, including first-order, second-order, interactive terms (e. g. AC, AC X AC, AC X HC), the insignificant parameters were then deleted until the significance of all parameters reaches 0.01. This equation was then compared with the Hadlock equation, Combs equation and Stirnemann equation by estimation error.

Data not involved in model establishment were collected as a validation set to verify the accuracy of different equations. The statistical software package IBM SPSS 24.0 (IBM Inc., New York) was used for the data analyses.

Results

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A total of 2000 clinical data were collected, of which 1925 were eligible for screening after post-hoc exclusion. These pregnant women who aged from 19 to 35, with an average age of 29. The mean time of ultrasound examination was 2.44 days before delivery. In order to reduce the estimation error of the model, the fetal weight compensation equation was established in this study: $\nabla \text{Weight} = -35534.421687 + 1909.952928 * \nabla \text{GA} - 23.412541 * (\nabla \text{GA}^2)$ (Weight unit:g; The unit of gestational week: weeks) .

Through the fetal weight compensation equation, the weight data of 1925 cases were modified to obtain the weight measured by ultrasound. Table 1 shows the fitting equation of fetal weight estimate and their correlation coefficients ($R^2 = 0.974$) as well as the standard error. Then, reverse knockout regression was used to establish the Chongqing fetal weight prediction equation: $\text{Log}_{10}(\text{EFW}) = 3.002741 + 0.00005944 * (\text{BPD}^2) + 0.00000222 * (\text{HC}^2) - 0.000002078 * (\text{AC}^2) + 0.00004262 * (\text{FL}^2) - 0.008753 * \text{BPD} - 0.000884 * \text{HC} + 0.003206 * \text{AC} - 0.002894 * \text{FL}$ (BPD: mm; HC: mm; AC: mm; FL: mm).

Table 1 Weight estimation equation

Variable	Estimate	SE	P-value	R ²
Intercept	3.002741	0.041		
BPD	-0.008753	0.001		
HC	-0.000884	0.000		
AC	0.003206	0.000		
FL	-0.002894	0.001	<0.001	0.974
BPD ²	0.00005944	0.001		
HC ²	0.00000222	0.001		
AC ²	-0.000002078	0.000		
FL ²	0.00004262	0.000		

SE, standard error; BPD, biparietal diameter; HC, head circumference; AC, abdominal circumference; FL, femur length; The P-value of less than 0.05 indicates statistical significance. R² is based on randomly selected one sample for each participant.

The newly established equation was compared with three representative weight prediction equations, which were respectively proposed by Hadlock, Combs and Stirnemann et al. Table 2 displays the comparison of the establishment methods for the four equations. The four equations were all multiple parameter evaluation equations, except fetal HC measurement method was slightly different, the

measurement method of other indicators was the same. The results might be somewhat affected, but they were comparable.

Table 2 Contrast four equations

Model	Sample	Scope	Race	Creation method
Chongqing	1925	Regional	Single	Compensation mechanism
Hadlock	167	Regional	Single	Stepwise regression
Combs	865	Regional	Multiple	Multiple linear regression
Stirnemann	2404	Multicentre	Multiple	Second-degree fractional polynomial

Firstly, this study compared the estimated errors of the four equations for each gestation week(Fig. 1). This estimation error was cited as the difference between the estimated weight and the compensated weight. Only when the pregnancy was 37 weeks, the mean absolute error and standard deviation of Chongqing equation were not the least among the four equations. It was found the mean absolute error of the Chongqing equation established in this study was 179.06 g, 171.63 g, 175.88 g, 192.20 g and 174.54 g respectively from 38 to 42 weeks of gestation, which was the smallest error of the four equations in each gestational period. The standard deviation of the Chongqing equation was 139.14 g, 136.76 g, 146 g, 136.57 g and 126.64 g respectively from 38 to 42 weeks of gestation, which was the smallest standard deviation of the four equations in each gestational period.

Secondly, we compared the estimated errors of the four equations again(Fig. 2). This estimation error was cited as the difference between the estimated weight and the birth weight. Estimate error $\pm 1.96x$ standard deviation interpreted as 95% error within this range. The estimated weight per gestational week estimated by the Chongqing equation at 37 to 42 weeks of gestation was the closest of the four equations to the actual average weight, while the weight estimation equation established by Hadlock and Combs had the largest error.

In order to further verify the accuracy of the Chongqing equation, gestational age was not considered, the mean absolute error and standard deviation of the estimation error of the equation established in this study were 178.9 g and 140.3 g respectively. The new equation had the smallest estimation error and the smallest standard deviation, so the new equation was more accurate for the prediction of fetal weight in Chongqing(Table 3).

Table 3 Comparison of estimation error in the establishment set

Model	Mean absolute error	Standard deviation
Chongqing fetal weight estimation equation	178.9	140.3
Hadlock fetal weight estimation equation	234.1	178.0
Combs fetal weight estimation equation	236.3	182.9
Stirnemann fetal weight estimation equation	221.3	176.1

Another 300 validation sets were collected to verify the accuracy of the new equation. It could be discovered from Table 4 that the mean absolute error and standard deviation of the estimation error of the Chongqing equation were 173.08 g and 128.59 g respectively. Both the mean absolute error and standard deviation were the smallest of the four equations in the validation sets, so the application of this equation to the clinical EFW would get a better result.

Table 4 Comparison of estimation error in the validation set

Estimation error	In this study	Hadlock	Combs	Stirnemann
Mean absolute error	173.08	180.65	207.19	188.23
Standard deviation	128.59	143.76	152.83	148.61

Discussion

Prenatal ultrasound can accurately predict fetal weight, so as to timely detect giant infants, reduce unnecessary trial delivery, and avoid maternal and infant injuries such as cervical laceration, shoulder dystocia, bone and brachial plexus injury[19–21]. It can reduce the increase of selective cesarean section rate caused by incorrect EFW and insufficient confidence of pregnant women in trial delivery[22]. It can also be found that very low weight infants, fully estimate the tolerance of the fetus to hypoxia during contractions, timely choice of cesarean section termination of pregnancy, to avoid adverse perinatal outcomes[23–24]. Both Kiserud et al.[3] and Gardosi et al.[25] showed that there were normal physiological changes between different countries and nations, and a single universal standard was not appropriate for everyone. Therefore, the purpose of this study was to create and verify the optimal

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In previous studies[4–6], they all ignored the difference between ultrasonic measurement time and birth time, and directly used the data measured during the last ultrasonic examination to correspond to birth weight, thereby calculating the estimated fetal weight, which would result in a large estimate. A weight compensation mechanism was established to compensate for the difference between the weight measured by ultrasound and the birth weight. We found the mean absolute error of the Chongqing equation established in this study was 179.06 g, 171.63 g, 175.88 g, 192.20 g and 174.54 g respectively from 38 to 42 weeks of gestation, which was the smallest error of the four equations in each gestational period. The standard deviation of the Chongqing equation was 139.14 g, 136.76 g, 146 g, 136.57 g and 126.64 g respectively from 38 to 42 weeks of gestation, which was the smallest standard deviation of the four equations in each gestational period. It could be seen from Fig. 1 that except for 37 weeks, the estimation error of Chongqing equation was the smallest for other gestational weeks. This might be because there were only 63 pregnant women collected at 37 weeks, with a small sample size. Further discussion is needed. The optimal regression equation for EFW in this region was established through the weight compensation mechanism. As Skupski research showed[18], the significant difference of the formula couldn't be calculated. The accuracy of the new equation and other representative equations was prospectively verified by comparing the estimation error. We analyzed not only the estimated error of each gestational week, but also the overall estimated error. The estimation error was the error of estimation weight and compensation weight, and the error of estimation weight and birth weight. The estimated weight per gestational week estimated by the Chongqing equation at 37 to 42 weeks of gestation was the closest of the four equations to the actual average birth weight. In the sets established by 1925 data, the mean absolute error and standard deviation of the estimation error of the equation established in this study were 178.9 g and 140.3 g respectively. In the 300 validation sets, the mean absolute error and Standard deviation of Chongqing equation were 173.08 g and 128.59 g respectively. The equation established in this study has the smallest mean absolute error and the smallest standard deviation. Therefore, compared with other equations, the fetal weight estimation equation established in this study was more applicable to Chongqing fetuses, and it could be used to obtain more accurate fetal weight estimation of Chongqing fetuses. This study has several unique advantages over previous studies. Firstly, we excluded ethnic and geographic factors and used multiple reverse elimination regression technique and the ten-fold cross verification method to establish the fetal weight prediction model. The method of deriving the equation can be extended to China and other parts of the world to establish a suitable reference equation for local fetal weight estimation. Secondly, we collected a large amount of data, specifically 1925 cases. They were carefully screened to ensure good health, excluding ethnic, geographic and other factors. Not only fetal structural abnormalities that may lead to adverse pregnancy outcomes were excluded, but patients with pregnancy complications were also excluded, all of which may affect the growth rate and development of the fetus, and affect the derivation and establishment of this formula. For example, the inclusion of gestational diabetes may increase the incidence of premature fetuses and macrosomia[27], leading to a decrease in the popularity of the equation. Finally, from the analysis of the comparative results, the equation established in this study had the least error and was most suitable for the prediction of Chongqing fetal weight. Compared with the representative equation, it was proved that

management of fetal weight. The limitation of this study is that the sonographers can see the data automatically display on the screen after measuring it, which may lead to the deviation of the expected value. Although we recruited well-trained ultrasound operators specifically instructed by the research procedure using internationally accepted techniques, different ultrasound doctors had slight operational difference that may lead to non-systematic errors. This study only collected data on pregnant women and fetuses from a hospital in Chongqing. The amount of data collected per gestational week was uneven.

Conclusions

Overall, The fetal weight prediction equation established in this study can more accurately predict the fetal weight in Chongqing. Accurate prediction of fetal gestational age and weight can be used to guide maternal delivery, select safe delivery mode and timing of delivery, reduce the incidence of postpartum complications and perinatal mortality, and provide a strong guarantee for the protection of maternal and infant health. Therefore, this equation has high clinical guidance and reference value for the monitoring and management of fetal weight and the process of maternal delivery.

Abbreviations

EFW, Estimated fetal weight; SE, standard error; BPD, biparietal diameter; HC, head circumference; AC, abdominal circumference; FL, femur length

Declarations

Ethics approval and consent to participate

All subjects recruited in this study agreed to participate and signed informed consent. The Study Review Board of our hospital approved the study protocol, with the protocol number 2016326.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable

Authors' contributions

LXD and WCHZ contributed the idea of the study and the drafting of the manuscript. SJF contributed the
Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js ed in participants selection and collection in the

field. All the authors reviewed and approved the final manuscript.

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Figures

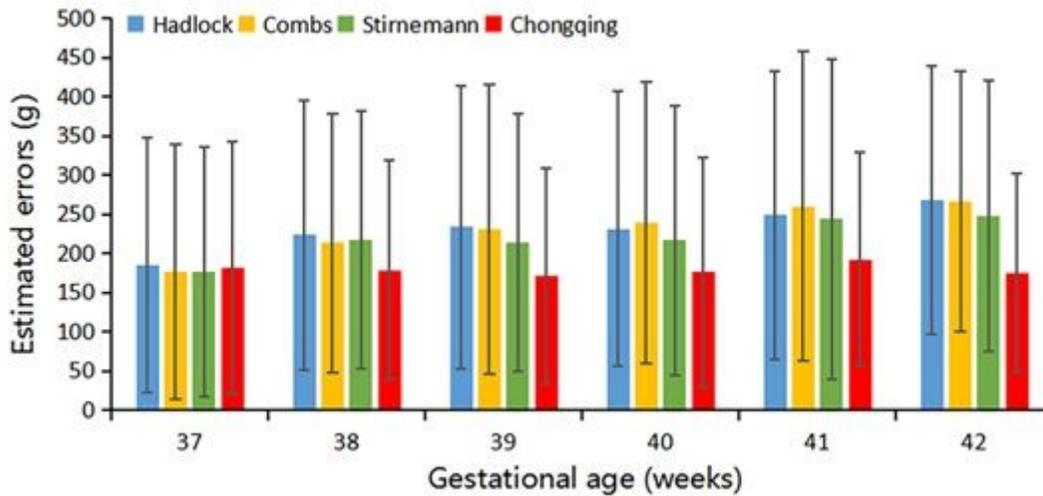


Figure 1

Comparison of estimated errors between estimated fetal weight and compensated weight for each gestation week

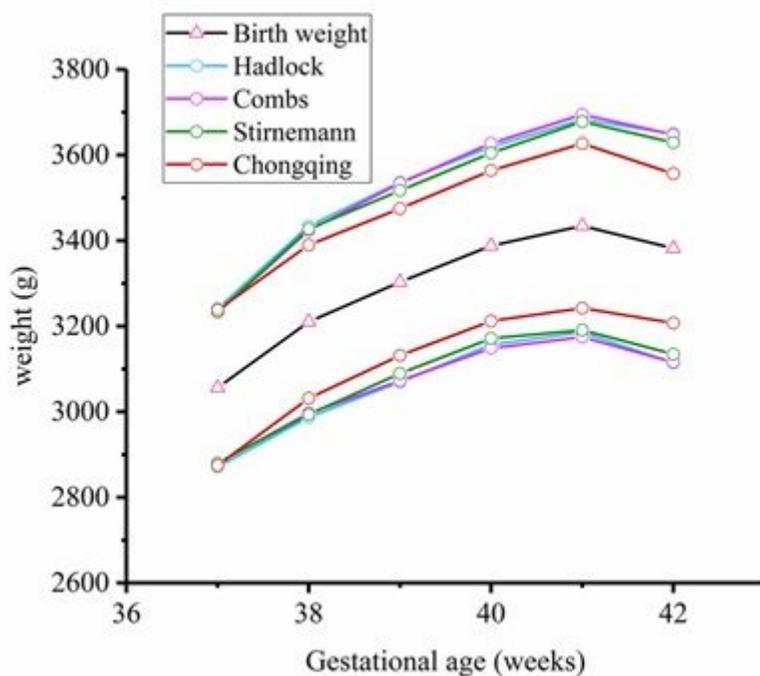


Figure 2

Comparison of estimated errors between estimated fetal weight and birth weight for each gestation week