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Original Research

Establishment of a New Equation for Ultrasonographic Estimated Foetal Weight in Chongqing: A Prospective Study

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Abstract

Background: Variations in foetal growth between populations should not be ignored, and a single universal standard is not appropriate for everyone. Therefore, it is necessary to develop a new ultrasound estimation equation that adapts better to regional population characteristics. The purpose of this study was to create a new equation for ultrasound estimation of foetal 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 child at full term in our hospital from December 2016 to November 2019. Foetal ultrasound parameters included biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur diaphysis length (FDL). The foetal weight compensation model was established by using the second-order linear regression model, and then, the foetal weight equation was established by utilizing the multiple reverse elimination regression technique. Last, the absolute error and relative error were used to compare the accuracy of the equations established in this study with representative equations. **Results**: Through the foetal weight compensation equation, the new equation suitable for Chongqing foetuses was successfully established with the variables of BPD, HC, AC, and FDL. The following foetal weight prediction equation was established in this study: $\text{Log}_{10}(\text{EFW}) = 3.002741 + 0.00005944 \times (\text{BPD}^2) + 0.00000222 \times (\text{HC}^2) - 0.000002078 \times (\text{AC}^2) + 0.00004262 \times (\text{FDL}^2) - 0.008753 \times \text{BPD} - 0.000884 \times \text{HC} + 0.003206 \times \text{AC} - 0.002894 \times \text{FDL}$ (BPD: mm; HC: mm; AC: mm; FDL: mm). In the sets established by the 1925 data, the mean absolute error and standard deviation of the estimation error of the new equation were 178.9 g and 140.3 g respectively. In the validation sets established with 300 data points, the mean absolute error and standard deviation of the new equation were 173.08 g and 128.59 g respectively. Compared with representative equations, the mean absolute error and the standard deviation of the new equation were the lowest. The equation established in this study better predicted foetal weight ($p < 0.001$). **Conclusions**: According to the local population characteristics of Chongqing, this study created a foetal weight estimation equation that is more accurate and suitable. This equation is clinically valuable for the monitoring and management of foetal weight.

Keywords: estimated foetal weight; prenatal ultrasound; Chongqing foetuses; regression equation; birth weight

1. Introduction

Estimated foetal weight (EFW) is an important part of antenatal care, and foetal weight is a key factor influencing the timing, manner and perinatal outcome of foetal delivery [1,2]. With the development of ultrasound technology, ultrasound estimation of foetal weight before birth has become one of the principal means for modern obstetrics to assess foetal weight, and identify and address high-risk pregnancies [3–5]. To obtain a good perinatal outcome, foetal weight can be dynamically monitored by ultrasound. Based on foetal biological parameters measured by ultrasound, scholars at home and abroad have derived several regression equations for EFW by multiple linear regression methods [6–10].

Most hospitals in China still use the Hadlock equation established in 1985 based on the US foetal database [7], probably because ultrasonic diagnostic instruments mostly default to this equation. Due to regional environments, racial differences [11], genetics, dietary factors [12] and other factors [13], the trunk ratio and fat content of foetuses in different regions may vary. Variations in foetal growth between populations should not be ignored. There may be some error in directly using the Hadlock equation to estimate foetal weight in Chinese foetuses. In recent years, the ultrasonographic equation suitable for Chinese Han population was also being explored in China to predict foetal weight [14,15]. Chongqing is the largest industrial and commercial city in southwest China. Chongqing has many ethnic groups and 30 million permanent residents [16]. Chinese residents have quite different physical conditions, due to differences in geography, ethnicity, socioeconomic status, and the living environment [17]. For example, the average height of Beijing residents is higher than that of Chongqing residents [18]. Therefore, to improve the accuracy of estimating foetal weight in the local population, it is necessary to identify a new and more accurate regression equation to estimate foetal weight according to the population characteristics of each different regions.

The aim of this study was first to establish the weight compensation equation, to make the ultrasonic measurement correspond to the foetal weight at the time of ultrasonic measurement and reduce the estimation error of the model. Then, we established the ultrasonographic estimation equation of foetal weight based on foetal growth parameters of pregnant women in Chongqing and compared this equation to the Hadlock equation [7], Combs equation [8] and Stirnemann equation [9] to ensure the accuracy of the new equation.

2. Materials and 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 whose gestational weeks ranged from 37 weeks to 41+6 weeks. All of them had a single gestation and the neonates were born with normal outcomes. All ultrasound examinations were performed using GE Voluson E8 and GE Voluson E10 machines (General Electric Healthcare, Tiefenbach, Oberoesterreich, Austria). The birth weights of all foetuses were determined with the electronic baby scale DY-1 (Shanghai Guangzheng Medical Instrument Co., LTD, Shanghai, China). This study involved 5 sonographers. All the sonographers received specific training, and their measurement techniques were subjected to rigorous quality assurance [19,20].

The inclusion criteria were as follows: pregnant women in various districts and countries in Chongqing; pregnant women who gave birth to a single child at full term; women who had a definitive knowledge of the gestational week (the definite last menstrual period was consistent with the gestational week corresponding to the crown-rump length measured by ultrasound); and women whose ultrasound examination was performed within 7 days before delivery.

The exclusion criteria were as follows: those with a structural foetal anomaly detected on ultrasound and patients who had complications during pregnancy (including gestational diabetes, gestational hypertension, and foetal growth restriction).

General information included maternal demographic data (ethnicity and age), data of the last menstrual period, pregnancy complications, gestational week at birth, birth data, ultrasonic examination dates, and new-born birth weight (each new-born was placed on an electronic scale after delivery by a senior nurse working in the delivery room).

Foetal ultrasound parameters included the biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur diaphysis length (FDL), all of which were measured in the last prenatal ultrasound.

The measurement methods were as follows [21,22]: foetal growth parameters were measured three times, and the mean values were taken. Foetal BPD and HC measurements were taken in a cross-sectional view of the foetal head at the level of the thalami, with an ideal angle of insonation of 90 degrees to the midline echoes. The appearance of both hemispheres was symmetrical. The continuous midline echo (falx cerebri) was broken in the middle by the cavum septi pellucidi and thalamus. The cerebellum was not visualized in the section. Linear distance was measured from the outer edge of the proximal to the outer edge of the distal skull. Foetal HC containing no extracranial soft tissue along the outer edge of the foetal skull was directly measured using the elliptical function key.

Foetal AC measurements were taken in a transverse-section view of the foetal abdomen as circular as possible, showing the stomach bubble, and umbilical vein at the level of the portal sinus. The kidneys and bladder did not have to be visible. The AC was measured at the outer surface of the skin line, directly with ellipse callipers.

Foetal FDL was imaged optimally, with both ends of the ossified metaphysis clearly visible. The longest axis of the ossified diaphysis was measured. An angle between the femur and insonating ultrasound beams between 45 degrees and 90 degrees was acceptable. Each calliper was placed at the ends of the ossified diaphysis without including the distal femoral epiphysis if it was visible. This measurement excluded triangular spur artefacts.

Statistical Analysis

To make the ultrasonic measurement correspond to the foetal weight at the time of ultrasonic measurement, a weight compensation equation was established. Taking gestational age at ultrasonography as the independent variable and birth weight as the dependent variable, a second-order linear regression model was used to establish the weight compensation equation for the changes with time to compensate for the difference between the weight and the birth weight during ultrasonic measurement at the time of ultrasonic measurement. The foetal weight prediction model was established by reverse elimination regression after compensating for the weight difference [23].

Reverse elimination is a method to select all independent variables into the regression model. All variables will be entered into the model, and tested with a T-test. Denote the smallest value T as T_L and compare it with T_0. If $T_L < T_0$, delete its variable in the model and fit the rest of variables in the regression model. Repeat the steps above until all the independent variables can't be eliminated.

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

Table 1. Characteristics of the Study Population (N = 1925).

Characteristic	Value
Age	29.00 ± 6.24
Neonatal birth weight (g)	3335.91 ± 367.22
Neonatal height (cm)	50.13 ± 1.27
Neonatal sex	
Male	957 (49.71%)
Female	968 (50.29%)
Delivery mode	
Natural labour	709 (36.83%)
Caesarean section	1216 (63.17%)

Table 2. Weight estimation equation.

Variable	Estimate	SE	p-value	adjusted R^2
Intercept	3.002741	0.041		
BPD	–0.008753	0.001		
HC	–0.000884	0.000		
AC	0.003206	0.000		
FDL	–0.002894	0.001	<0.001	0.974
BPD^2	0.000005944	0.001		
HC^2	0.00000222	0.001		
AC^2	–0.000002078	0.000		
FDL^2	0.00004262	0.000		

SE, standard error; BPD, biparietal diameter; HC, head circumference; AC, abdominal circumference; FDL, femur diaphysis length; a p-value of less than 0.05 indicates statistical significance. adjuested R^2 is based on one randomly selected sample for each participant.

Data not involved in model establishment were collected as a validation set to verify the accuracy of different equations. Microsoft Excel is used as a data collection tool. The statistical software package IBM SPSS 24.0 (IBM Inc., Armonk, NY, USA) was used for the data analyses.

3. Results

A total of 2000 foetal data points were collected, of which 1925 foetal data points were eligible for screening after post hoc exclusion. Table 1 lists the details of the individual women. The mean time of ultrasound examination was 2.44 days before delivery. To reduce the estimation error of the model, the following foetal weight compensation equation was established in this study: ∇Weight = –35534.421687 + 1909.952928 × ∇GA – 23.412541 × (∇GA^2) (Weight unit: g; gestational age unit: weeks). Compensation weight was the difference between the time of birth and the time of ultrasound examination in the weight compensation formula.

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

The newly established equation was compared with three representative weight prediction equations, which were proposed by Hadlock *et al.* [7], Combs *et al.* [8] and Stirnemann *et al.* [9]. Table 3 displays the comparison of the establishment methods for the four equations. The four equations were all multiple parameter evaluation equations, except the foetal HC measurement method, which was slightly different, and the measurement method of other indicators was the same. The results might be somewhat affected but comparable.

First, this study compared the estimated errors of the four equations for each gestational week (Fig. 1). This estimation error was cited as the difference between the estimated weight and the compensated weight. It was found that the mean absolute error values of the Chongqing equation established in this study were respectively 179.06 g, 171.63 g, 175.88 g, 192.20 g and 174.54 g for gestational weeks 38 to 42 and were the smallest error values among the four equations in each gestational period. The standard deviations of the Chongqing equation were respectively 139.14 g, 136.76 g, 146 g, 136.57 g and 126.64 g for gestational weeks 38 to 42 and were the smallest standard deviations among the four equations in each gestational period.

Next, 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. The estimated error ± 1.96× standard deviation was 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.

To further verify the accuracy of the Chongqing equation, gestational age was not considered, and 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 (Table 4). The new equation had the smallest estimation error and the smallest standard deviation, and the new equation was more accurate for the prediction of foetal weight in Chongqing ($p < 0.001$).

Another 300 foetal data points were collected to verify the accuracy of the new equation, and they constituted the validation sets. These pregnant women were aged from 18 to 40 years, with an average age of 28 years. The mean time of ultrasound examination was 0.84 days before delivery.

Table 3. The 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

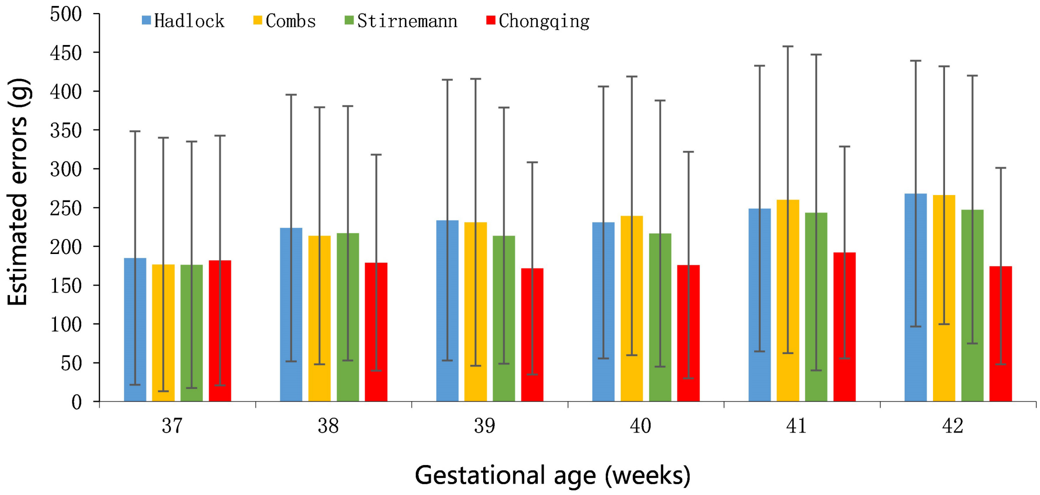

Fig. 1. Comparison of estimated errors between estimated foetal weight and compensated weight for each gestational week.

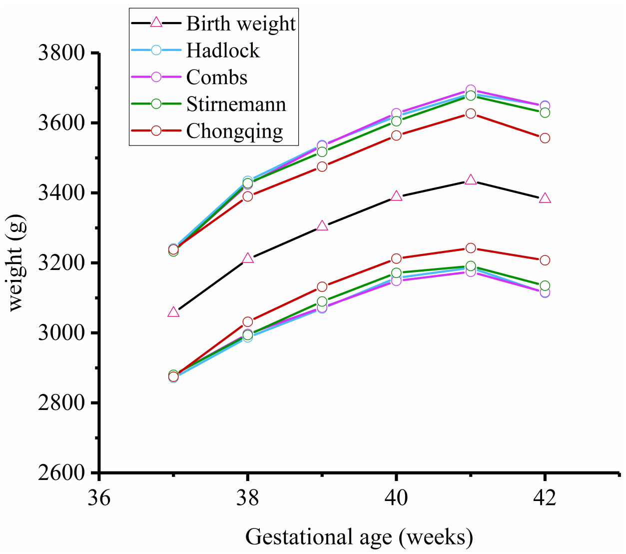

Fig. 2. Comparison of estimated errors between estimated foetal weight and birth weight for each gestational week.

Table 5 shows 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 of which were the smallest among the four equations in the validation sets. Therefore, the application of this equation to the clinical EFW would obtain a better result ($p < 0.001$).

Table 4. Comparison of estimation error in the establishment set.

Estimation error	In this study	Hadlock	Combs	Stirnemann	p
Mean absolute error	178.9	234.1	236.3	221.3	<0.001
Standard deviation	140.3	178.0	182.9	176.1	<0.001

A p-value of less than 0.05 indicates statistical significance.

Table 5. Comparison of estimation error in the validation set.

Estimation error	In this study	Hadlock	Combs	Stirnemann	p
Mean absolute error	173.1	180.7	207.2	188.2	<0.001
Standard deviation	128.6	143.8	152.8	148.6	<0.001

A p-value of less than 0.05 indicates statistical significance.

4. Discussion

The foetal weight prediction equation was established in this study. Prenatal ultrasound can accurately predict foetal weight to detect giant infants in a timely manner, reduce unnecessary trial delivery, and avoid maternal and infant injuries such as cervical laceration, shoulder dystocia, and bone and brachial plexus injury [24]. It can also reduce the rate of selective caesarean caused by incorrect EFW and insufficient confidence of pregnant women in a trial of delivery [25]. In addition, prenatal ultrasound can identify very-low-birth-weight infants and fully estimate the foetus's tolerance to hypoxia during contractions so that the doctor can choose timely caesarean section to deliver the pregnancy and avoid adverse perinatal outcomes [26,27].

Both Kiserud *et al*. [5] and Gardosi *et al*. [28] showed that there are normal physiological changes between different countries and nations and that a single universal standard is not appropriate for everyone. Therefore, the purpose of this study was to establish the weight compensation equation, which is used to make the ultrasonic measurement correspond to the foetal weight at the time of ultrasonic measurement and reduce the estimation error of the model. Then, we created and verified the optimal regression equation for predicting foetal weight, according to the population characteristics of Chongqing.

Because the timing of delivery was uncontrollable, prenatal ultrasound was performed every 7 days after 37 weeks of gestation. The ultrasound examination time was extended to 7 days. Previous some studies 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 to calculate estimated foetal weight, which would result in a large estimate. The relationship between gestational age and birth weight was established by a nonlinear regression equation. For example, we can use the weight compensation equation to calculate the foetal weight at 37 weeks of gestation, when the ultrasound examination is performed at 37 weeks of gestation and the foetus is born at 38 weeks of gestation. A weight compensation mechanism was established to compensate for the difference between the weight measured by ultrasound and the birth weight.

We found that the mean absolute error values of the Chongqing equation established in this study were respectively 179.06 g, 171.63 g, 175.88 g, 192.20 g and 174.54 g from 38 to 42 weeks of gestation and that these error values were the smallest of the four equations in each gestational period. The standard deviations of the Chongqing equation were repectively 139.14 g, 136.76 g, 146 g, 136.57 g and 126.64 g from 38 to 42 weeks of gestation and were the smallest standard deviations among the four equations in each gestational period. The estimation error of the Chongqing equation was not the smallest at 37 gestational weeks. This might be because there were data from only 63 pregnant women were collected at 37 weeks, making this a small sample size. Further discussion is needed.

The optimal regression equation for EFW in this region was established through the weight compensation mechanism. The accuracy of the new equation and other representative equations was prospectively verified by comparing the estimation error. We analysed not only the estimated error of each gestational week but also the overall estimated error. The estimation error was the error of the estimation weight and compensation weight and the error of the 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 the 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 validation sets established with 300 data points, the mean absolute error and standard deviation of the Chongqing equation were 173.08 g and 128.59 g, respectively. The equation established in this study was the most accurate in predicting foetal weight in Chongqing ($p < 0.01$). Therefore, compared with other equations, the foetal weight estimation equation established in this study was more applicable to Chongqing foetuses, and it could be used to obtain a more accurate foetal weight estimation of Chongqing foetuses.

This study has several unique advantages over previous studies. First, we excluded ethnic and geographic factors and used the multiple reverse elimination regression technique and the ten-fold cross verification method to establish the foetal weight prediction model. The method for deriving the equation can be extended to China and other parts of the world to establish a suitable reference equation for local foetal weight estimation. Second, we collected a large amount of data, specifically data from 1925 cases. They were carefully screened to ensure good health, excluding ethnic, geographic and other factors. Foetal structural abnormalities that may lead to adverse pregnancy outcomes were excluded, and patients with pregnancy complications were also excluded, as all of these factors may affect the growth rate and development of the foetus, and affect the derivation and establishment of this formula. For example, the inclusion of gestational diabetes may increase the incidence of premature foetuses and macrosomia [29], leading to a decrease in the uptake 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 foetal weight. Compared with the representative equation, it was proven that the application of this equation had high clinical guidance and reference value for the monitoring and management of foetal weight. In order to identify abnormal growth trajectories more quickly, we can study local curve population further [30].

The limitation of this study is that the sonographers could see the data automatically display on the screen after performing the measurements, which may lead to the deviations from the expected value. Although we recruited well-trained ultrasound operators specifically instructed by the research procedure using internationally accepted methods, different ultrasound doctors had slight operational differences that may have led to non-systematic errors [31]. This study only collected only data on pregnant women and foetuses from a hospital in Chongqing. The amount of data collected per gestational week was uneven.

5. Conclusions

Overall, the foetal weight prediction equation established in this study can more accurately predict foetal weight in Chongqing. Accurate prediction of foetal gestational age and weight can be used to not only assess the growth and development of the foetus, but also guide the timing and mode of delivery of a pregnancy. It can reduce the incidence of postpartum complications and perinatal mortality, and provide a strong guarantee for the health of both mothers and infants. Therefore, this equation is clinically valuable for monitoring and managing foetal weight.

Abbreviations

EFW, estimated foetal weight; SE, standard error; BPD, biparietal diameter; HC, head circumference; AC, abdominal circumference; FDL, femur diaphysis length.

Author Contributions

XDL, XJD, and CHZW contributed to the idea of the study and the drafting of the manuscript. JFS contributed to the statistical analysis. LYC, XRD, FLZ, YS and MCZ contributed to participant selection and data collection in the field. All the authors reviewed and approved the final manuscript.

Ethics Approval and Consent to Participate

All subjects recruited in this study agreed to participate and signed informed consent forms. The Study Review Board of The Second Affiliated Hospital of Chongqing Medical University approved the study protocol, with protocol number 2016326.

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Conflict of Interest

The authors declare no conflict of interest.

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