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A validation study of ultrasonic foetal weight estimation models for Hong Kong Chinese singleton pregnancies

應用於香港華籍單胎妊娠婦女的超聲波胎兒體重估測模式：效度研究

Objective. To validate the published regression models for ultrasonic foetal weight estimation in Hong Kong Chinese singleton pregnancies.
Design. Prospective cohort study.
Setting. Regional hospital, Hong Kong.
Participants. One hundred and fourteen Hong Kong Chinese women with singleton pregnancy at term (37-42 weeks).
Main outcome measures. The birth weight of the neonate was used to validate the ultrasonic foetal weight estimation models. The ultrasound used to collect the data was performed within 2 days prior to delivery.
Results. Foetal weight estimation models published by Hadlock and Woo have a high intraclass correlation coefficient of 0.86. Woo's regression model has the least mean difference (0.2 g; 95% limits of agreement, -569.4 to 569.8 g) and Hadlock 3 has the smallest limits of agreement (-114.6 g; 95% limits of agreement, -663.4 to 434.2 g) among the models tested.
Conclusions. Woo's regression model of foetal weight estimation gave the least mean difference and the actual birth weight for our local population were within the acceptable limits of agreement.

目的：透過香港華籍單胎妊娠婦女，評估已發表的超聲波胎兒體重估測回歸模式的效度 。
設計：前瞻性隊列研究。
安排：一所分區醫院，香港。
參與者：114 位香港華籍單胎妊娠婦女，懷孕期介乎 37 至 42 週。
主要結果測量：透過新生兒的出生體重，評估超聲波胎兒體重估測模式的效度，並於胎兒出生前兩天內以超聲波估測其體重。
結果：由 Hadlock 及 Woo 所發表的兩個胎兒體重估測模式所得出的組間相關係數甚高，達0.86。Woo 的回歸模式得出最小平均差值 (0.2克；95%一致性區間，569.4至569.8克)，而 Hadlock 的第三模式則得出最小一致性區間 (-114.6克；95%一致性區間， 663.4 至 434.2 克)。
結論：Woo的胎兒體重估測回歸模式得出最小平均差值，而新生兒的實際出生體重亦在可接受的一致性區間內。

Key words:
Birth weight;
Fetal weight;
Infant, newborn;
Pregnancy;
Ultrasonography

關鍵詞：
出生體重；
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Introduction

The birth weight is the key factor for the outcome of in utero growth of the foetuses. It has been well recognised that foetuses at the extremes of the normal birth weight range are associated with increases in perinatal morbidity, mortality, and adverse developmental outcomes.[1] In addition, macrosomic infants have a 6-fold increase of marked birth trauma.[2] The antenatal foetal weight measurement is of tremendous importance because it can give us useful information for the foetal growth assessment. This information could help us decide the time of delivery, the need for specific obstetrical intervention, and whether it is necessary for the delivery to be at a centre equipped with intensive neonatal care support.

At present, two-dimensional ultrasonography (USG) is the most widely

Table 1. Published models for ultrasonic foetal weight estimation

Model	Formula*
Hadlock 1[5]	Log EFW=1.304+0.05281 (AC)+0.1938 (FL)-0.004 (AC x FL)
Hadlock 2[5]	Log EFW=1.335-0.0034 (AC x FL)+0.0316 (BPD)+0.0457 (AC)+0.1623 (FL)
Hadlock 3[5]	Log EFW=1.326-0.00326 (AC x FL)+0.0107 (HC)+0.0438 (AC)+0.158 (FL)
Hadlock 4[5]	Log EFW=1.3596-0.00386 (AC x FL)+0.0064 (HC)+0.00061 (BPD x AC)+0.0424 (AC)+0.174 (FL)
Shepard[6]	Log EFW=–1.7492+0.166 (BPD)+0.046 (AC)-2.646 (AC x BPD)/1000
Warsof[7]	Log EFW=–1.599+0.144 (BPD)+0.032 (AC)-0.111 (BPD^2 x AC)/1000
Campbell[8]	Ln EFW=–4.564+0.282 (AC)-0.00331 $(AC)^2$
Woo 1[9]	Log EFW=1.13+0.181864 (BPD)+0.0517505 (AC)-3.34825 x 10^{-3} (BPD x AC)
Woo 2[9]	Log EFW=1.13705+0.15549 (BPD)+0.04864 (AC)-2.79682 x 10^{-3} (BPD x AC)+0.037769 (FL)-4.94529 x 10^{-4} (FL x AC)

* EFW denotes estimated foetal weight, AC abdominal circumference, FL femur length, HC head circumference, and BPD biparietal diameter

accepted method to estimate foetal weight. This method has been in use for more than three decades, and is by far the most extensively studied modality of birth weight estimation.[3] Various investigators have generated models for foetal weight estimation using different combinations of foetal biometric parameter measurements.[4-9] To date, there is no consensus as to which model gives a better validity in clinical application. The decision to use a particular model is based on the preference of the individual clinician.

Most of the foetal weight estimation models have been derived from data from western populations.[4-8] Ethnicity and secular changes have been known to affect birth weight[10-14]; hence, birth weight models derived from other ethnic populations applied in our locality, without the validation of their clinical applicability, might result in systemic erroneous estimations. In the 1980s, Woo et al[9] published models of ultrasonic foetal weight estimations within Hong Kong. It has been demonstrated that birth weight standards change over time[13,14]; therefore, we believe that it is necessary to regularly revalidate the models derived in the past in our local population. The aim of this study is to test the validity of the published ultrasonic foetal weight estimation models using data from Hong Kong Chinese women collected in 2003.

Methods

This is a prospective observational study from January to March 2003 conducted in a tertiary obstetric unit, Prince of Wales Hospital, Hong Kong. The parturient women in the unit consisted of both high-risk and low-risk cases and over 98% were ethnic Chinese. The subjects were invited to participate in this study when they attended our antenatal ward. The inclusion criteria were as follows:

1. the couple were both ethnic Chinese;
2. singleton pregnancies;
3. term pregnancies (37-42 weeks); and
4. the gestational age was verified with antenatal USG performed prior to 20 weeks of gestation.

Pregnancies that were complicated by congenital abnormalities and those that were delivered more than 2 days after the ultrasound examination were excluded from the validation study. Written consent was obtained from the participants and the study protocol was approved by the institutional review board. The ultrasound examinations were specifically arranged for this study and foetal biometric USG was performed on all subjects.

The foetal-measured parameters included biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL). All examinations were performed by two experienced operators using an ATL 5000 USG machine (ATL, A Philips Medical System Company, Washington, US) with a 3.5-MHz curvilinear probe. Foetal head measurements were made along the axial plane at the level where the continuous midline echo is broken by the septum pellucidum cavum in the anterior third.[15] Measurements of the BPD were made from the proximal echo of the foetal skull to the side of the border deep distal to the ultrasound beam. The HC was measured by using the elliptical callipers over the four points of the BPD and occipital-frontal diameter which was measured in the same plane between the leading edge of the frontal bone and the outer border of the occiput.[15] The foetal AC was measured on a transverse section through the foetal abdomen as described by Campbell and Wilkin.[16] The femur was identified and the transducer rotated until the full femoral diaphysis was seen in a plane as close to right angles to the ultrasound beam as possible. A straight measurement from one end of the diaphysis to the other end was then made.[17]

The neonates were weighed using one Detecto digital baby scale (Detecto, Missouri, US) immediately after birth. The obstetric management was determined by the attending obstetricians, who were not involved in this study. Table 1 shows the foetal estimation models that were validated in the present study. They were selected because of their general acceptance in clinical practice for foetal weight estimations. An intraclass correlation coefficient value of greater than 0.75 was set as a priori to indicate the minimum acceptable level of validity.[18] A sample size of 81 subjects was required to give a power of 80% with an alpha of 0.05.[18] Before the commencement of the study, the interobserver agreement of the individual USG foetal biometric parameters was established. The measurements (mean difference, 95% limits of agreement in centimeters) were -0.10, -0.14 to -0.06 for BPD; -0.65, -0.86 to -0.45 for

Intraclass correlation coefficient=σ^2 subject / (σ^2 subject+ σ^2 measurement method+ σ^2 error)

where
σ^2 subject is the variance in actual birth weights between subjects
σ^2 measurement method is the variance in foetal weight between the ultrasonic estimations and the actual birth weights
σ^2 error is the measurement error

HC; 0.33, 0.04 to 0.61 for AC; and -0.08, -0.12 to -0.03 for FL.

The Statistical Package for the Social Sciences (Windows version 10.0; SPSS Inc, Chicago, US) was used for the data analysis. The concordance of assessing validity of various regression models for foetal weight estimation was determined by the intraclass correlation coefficient and limits of agreement method.[19,20] The actual birth weight was used as the gold standard for comparison. The intraclass correlation coefficient provides a quantitative assessment of the variability inherent in the various regression models for foetal weight estimations from the spread of the results. The mathematics is shown in the Box.[19] The mean difference and limits of agreement method is able to distinguish between the systematic and random bias. The mathematics of the 95% limits of agreement of the difference in estimated foetal weight and actual birth weight was as follows[20]:

Limits of agreement=mean difference±1.96 x SD*

* Standard deviation

Results

One hundred and fourteen subjects gave consent for the study and all had ultrasound examinations. One hundred and nine women delivered within 2 days of the USG scan. Five participants were excluded from the analysis, three of them were discharged home with no follow-up, and two delivered more than 3 days after the ultrasound examination.

The mean gestation age at study was 40.4 (standard deviation, 1.4) weeks. Among the 109 participants, 11.9% (13/109) had natural onset of labour, 59.6% (65/109) had labour-induced delivery, and 28.4% (31/109) had elective Caesarean section.

Table 2. Ultrasonic foetal biometry, estimated birth weight, and actual birth weight of the study population

Parameter	Biometry, n=109 Mean (SD*)
Biparietal diameter (cm)	9.3 (0.4)
Head circumference (cm)	32.9 (1.2)
Abdominal circumference (cm)	34.1 (2.2)
Femur length (cm)	7.1 (0.3)
Actual birth weight (g)	3365.0 (362.5)
Estimated foetal weight (g)	
Hadlock 1	3280.2 (475.9)
Hadlock 2	3374.9 (478.1)
Hadlock 3	3224.7 (444.4)
Hadlock 4	3311.1 (466.4)
Shepard	3523.9 (523.6)
Warsof	3356.2 (507.6)
Campbell	3291.0 (416.6)
Woo 1	3501.1 (485.2)
Woo 2	3339.6 (446.3)

* SD standard deviation

Table 3. Distribution of actual birth weight of neonates

Birth weight group (g)	No. of neonates, n=109
2500-2999	16
3000-3499	55
3500-3999	34
4000-4499	4

Table 4. Intraclass correlation coefficients of ultrasonic foetal weight estimation and actual birth weight

Published model	Intraclass correlation coefficient (95%CI*), n=109
Hadlock 1	0.84 (0.76, 0.89)
Hadlock 2	0.85 (0.78, 0.90)
Hadlock 3	0.86 (0.80, 0.91)
Hadlock 4	0.86 (0.79, 0.91)
Shepard	0.82 (0.73, 0.88)
Warsof	0.82 (0.73, 0.88)
Campbell	0.79 (0.69, 0.86)
Woo 1	0.83 (0.75, 0.89)
Woo 2	0.86 (0.79, 0.90)

* CI confidence interval

Table 5. Mean difference and 95% limits of agreement in ultrasonic foetal weight estimation and actual birth weight

Published model	Mean difference (g)	95% limits of agreement (g)
Hadlock 1	-63.7	-686.6 to 559.2
Hadlock 2	35.5	-561.7 to 632.7
Hadlock 3	-114.6	-663.4 to 434.2
Hadlock 4	-28.3	-606.3 to 549.7
Shepard	184.6	-516.5 to 885.7
Warsof	16.8	-660.6 to 694.2
Campbell	-52.9	-703.2 to 597.4
Woo 1	161.7	-484.3 to 807.7
Woo 2	0.2	-569.4 to 569.8

The mean of the individual foetal biometric measurement (BPD, HC, AC, and FL), the estimated birth weights using the different models, and the actual birth weights of this study are shown in Table 2. Table 3 shows the distribution of the actual birth weights of the neonates. None of the participants delivered a neonate of birth weight of 2500 g or lower, and 3.7% (4/109) delivered neonates of birth weight of 4000 g or higher. The intraclass correlation coefficient and the 95% confidence interval of each model tested are shown in Table 4. Hadlock 3, Hadlock 4, and Woo 2 models have the highest intraclass correlation coefficient of 0.86 among the models tested in the study. Table 5 shows the mean difference and the limits of agreement between the ultrasonic foetal weight estimations using the tested models and the actual birth weights. The Woo 2 model has the least mean difference (0.2 g) of the estimated birth weights, and the Hadlock 3 model has the smallest limits of agreement (-663.4 to 434.2 g).

Discussion

The results of this validation study shows that all the models tested give an acceptable estimate of concordance in foetal weight estimation based on the intraclass correlation coefficient alone. The three models (Hadlock 3, Hadlock 4, and Woo 2) had better agreement because they have the highest intraclass correlation coefficient among the models tested. When the mean difference was examined, the Woo 2 model had the least systematic bias with the acceptable limit of agreement (0.2 g; limits of agreement, -569.4 to 569.8 g). Hadlock 3 had the smallest limit of agreement (-663.4 to 434.2 g), and the systematic bias was -114.6 g. The results from this validation study exemplifies the potential problems of the use of correlation coefficient alone to compare two methods of clinical measurement because the strength of relation between two variables but not the agreement between them is assessed.[20]

Previous studies have shown that models that use all the parameters of foetal HC, AC, and FL tend to give a closer estimate of the true birth weight.[9,21,22] We have also observed the same phenomenon in the present study. Models using AC alone (Campbell model), or those using AC and FL alone tend to give a lower correlation with the actual birth weight. One might postulate that birth weight is dependent on both the structural size (as represented by the biometric HC and FL measurements) and fat store (as represented by AC), which are both important in contributing to the final birth weight of a foetus.

The findings in the present study suggest that ethnicity potentially plays an important role in the foetal body weight estimation. The study shows that the Woo 2 model produced the best estimate of the actual birth weight with the least difference in systematic bias and with acceptable limits of agreement. The reason for this agreement could be because our study subjects and Woo's study subjects are both derived from a local Chinese population. Despite a secular change of mean (standard deviation) birth weight from 3237 (366) g in 1984 to 3362 (370) g in 2003, the model is still presently valid.[14]

Regression models with the addition of HC parameter have been reported to produce better estimates of the final birth weight because variations in shape of foetal head could result in an erroneous estimation of the birth weight.[21] From the results of the present study, we cannot determine the contribution of HC to estimate the birth weight in our local population because HC was not included in the locally derived models. It would be interesting to see whether addition of HC to the Chinese models could further enhance the precision of birth weight estimation. The agreement of the different foetal weight estimation models has been shown to vary with different birth weight groups.[23] In our study, there were only a few neonates born with the extremes of birth weight. Further studies are necessary to establish valid birth weight estimation models for neonates with extremes of birth weight.

In conclusion, foetal ultrasound is a useful tool to estimate birth weight. Judicious selection of appropriate models for the local population is important to ensure precision in the assessment.

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