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Comparative Performance of Ultrasonographic Fetal Biometry and Three Clinical Equations in the Intrapartum Period for Estimating Fetal Weight in Thai Singleton Pregnant Women Giving Birth at a Referral Tertiary Hospital

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ABSTRACT

Objectives: To compare the accuracy of fetal weight estimation by ultrasonography and three clinical equations and also to examine the ability of these estimation methods to predict low birth weight and macrosomia in Thai pregnant women giving birth at a referral tertiary hospital in northeastern Thailand.

Materials and Methods: Two hundred singleton pregnant women giving birth at Sanpasitthiprasong Hospital during September 2018 – March 2019 were recruited. Fetal weight was estimated by trans-abdominal ultrasound and three existing clinical equations: Dare's, Johnson's and Buchmann's methods. Proportions of within 10% accuracy compared to actual birth weight were computed and measures of ability to predict low, normal birth weight and macrosomia (sensitivity/specificity, positive/negative predictive values and area under the receiver operating characteristics (AUR)) were compared using McNemar's test and nonparametric method.

Results: The mean actual birth weight was 3,069.9 ± 464.8 grams. Overall, ultrasonography resulted in a higher proportion of within-10% accuracy than Dare's, Johnson's and Buchmann's methods (70.5%, 38.5%, 24.5% and 58.5%, respectively, $p < 0.001$). Similar findings were observed for normal birth weight and for both term and preterm neonates. Ultrasonography had the best ability to predict low birth weight with sensitivity, specificity and AUR of 75% (95% confidence interval (CI) 51-91%), 94% (95%CI 89-97%) and 0.84 (95%CI 0.75-0.94), while Dare's and Johnson's methods better predicted macrosomia than the other two methods ($p = 0.002$).

Conclusion: Intrapartum ultrasonography had the highest accuracy in estimating actual birth weight, overall and particularly best in low birth weight. However, Dare's and Johnson's clinical equations appeared to predict macrosomia well and might probably be useful when large fetus is suspected in clinical practice.

Keywords: estimated fetal birth weight, ultrasonography, clinical equations, accuracy, predictive ability.

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การศึกษาเปรียบเทียบความสามารถในการทำนายน้ำหนักทารกในครรภ์ระหว่างการใช้อัลตราซาวด์และสมการทางคลินิก 3 สมการ ในระยะการคลอดในกลุ่มสตรีตั้งครรภ์ชาวไทยที่คลอดบุตรในโรงพยาบาลตติยภูมิ

นันทพงศ์ พงศ์ทิพากร, พงษ์สันต์ พันธะไชย, ปริญญา ชำนาญ

บทคัดย่อ

วัตถุประสงค์: *เพื่อเปรียบเทียบความถูกต้องในการคาดคะเนน้ำหนักทารกในครรภ์ระหว่างการใช้อัลตราซาวด์ และสมการทางคลินิก 3 สมการ และเพื่อเปรียบเทียบความสามารถในการทำนายทารกแรกเกิดที่มีน้ำหนักตัวน้อยและตัวโต ในกลุ่มสตรีตั้งครรภ์ชาวไทยที่คลอดในโรงพยาบาลตติยภูมิทางภาคตะวันออกเฉียงเหนือของประเทศไทย*

วัสดุและวิธีการ: *สตรีตั้งครรภ์ชาวไทยจำนวน 200 คน ที่คลอดบุตร ณ โรงพยาบาลสรรพสิทธิประสงค์ ระหว่างเดือนกันยายน พ.ศ. 2561 ถึง มีนาคม พ.ศ. 2562 จะได้รับการประเมินน้ำหนักทารกในครรภ์โดยการทำอัลตราซาวด์และใช้สมการทางคลินิก 3 สมการ (Dare's, Johnson's and Buchmann's equations) โดยทำการเปรียบเทียบค่าความแม่นยำภายในร้อยละ 10 (Within 10% accuracy) ของแต่ละวิธีเมื่อเปรียบเทียบกับน้ำหนักแรกเกิดจริง และเปรียบเทียบค่าความสามารถในการทำนายกลุ่มน้ำหนักทารกน้อย น้ำหนักปกติ และน้ำหนักเกินเกณฑ์ (sensitivity/specificity, positive/negative predictive values and area under the receiver operating characteristics (AUR)) โดยใช้สถิติ McNemar's test และ non-parametric method*

ผลการศึกษา: *ค่าเฉลี่ยของน้ำหนักทารกแรกเกิด ± ค่าเบี่ยงเบนมาตรฐานเท่ากับ 3,069.93 ± 464.84 กรัม จากการศึกษาโดยรวม ค่าความแม่นยำภายในร้อยละ 10 ของการประมาณค่าโดยใช้อัลตราซาวด์ สูงกว่าวิธีของ Dare's Johnson's และ Buchmann's (ความถูกต้องร้อยละ 70.5, 38.5, 24.5 และ 58.5 ตามลำดับ, $p < 0.001$) และผลการศึกษาก็คล้ายคลึงกันในกลุ่มน้ำหนักแรกเกิดที่น้ำหนักตัวปกติ และในกลุ่มของทารกก่อนกำหนดและครบกำหนดด้วย โดยอัลตราซาวด์มีความสามารถในการทำนายทารกน้ำหนักตัวน้อย (น้ำหนักตัวน้อยกว่า 2,500 กรัม) ได้ดีที่สุด โดยมีค่า sensitivity ที่ร้อยละ 75 (95% confidence interval 51-91%) ค่า specificity ร้อยละ 94 (89-97%) และพื้นที่ใต้โค้ง AUR 0.84 (0.75-0.94) แต่วิธีของ Dare's และ Johnson's มีความสามารถในการทำนายน้ำหนักทารกตัวโต (น้ำหนักแรกเกิดมากกว่า 4,000 กรัม) ที่สูงกว่าวิธีอื่น ($p = 0.002$)*

สรุป: *การอัลตราซาวด์ในระยะคลอดมีความถูกต้องในการประมาณการน้ำหนักทารกแรกเกิดสูงที่สุด และสามารถทำนายการมีทารกน้ำหนักน้อยได้ดีที่สุดเมื่อเทียบกับสมการทางคลินิกอื่น อย่างไรก็ตามสมการทางคลินิกของ Dare's และ Johnson's มีความสามารถในการทำทารกน้ำหนักเกินเกณฑ์ได้ดีที่สุดและอาจนำมาใช้ในเวชปฏิบัติเมื่อสงสัยการมีทารกตัวโต*

คำสำคัญ: *การประมาณการค่าน้ำหนักทารก, อัลตราซาวด์, สมการทางคลินิก, ความถูกต้อง, ความสามารถในการทำนาย*

Introduction

Assessment of fetal size is critical for decision making in routes and methods of delivery. Accurate estimation of fetal weight could help reduce the incidence of maternal and neonatal injury during labor and rate of inappropriate cesarean section[1, 2]. Additionally, fetal birth weight estimation may also be beneficial in predicting perinatal morbidity and mortality particularly in those with birth weight of the lower than the 10th percentile[3-5].

Assessing the size of the fetus can be accomplished in a number of ways: mother self-assessment based on prior pregnancy, estimation equations based on height of fundus and abdominal girth and ultrasonography, all of which are essentially assessor-dependent[6]. Equations based on ultrasonographic findings have been increasingly used, but some studies reported that these ultrasonography-based equations resulted in a systematic underestimation of fetal weight especially if the ultrasonography was performed during intrapartum period[7, 8]. Previous studies have showed inconsistent results concerning clinical equations that best predicted fetal birth weight. Some studies found that intrapartum ultrasonography better predicted fetal weight than other clinical equations[9-11], while other studies showed that Dare's equation and ultrasonography predicted fetal weight better than Johnson's equation in term normal weight fetus[12] and large fetus[6]. Furthermore, a few studies compared the predictive performance of several clinical equations[9-11, 13, 14], and most of the previous studies were performed in term low risk pregnancy[6, 10, 13]. Evidence on high risk group is limited[14]. Therefore, the present study primarily aimed to compare the performance of four methods to estimate fetal weight in low and high risk pregnancy: three existing standard clinical equations and ultrasonography-based estimation. The secondary objective was to examine the ability of these estimation methods to predict low birth weight and macrosomia in Thai pregnant women giving births at a referral tertiary hospital in northeastern Thailand.

Materials and Methods

In this observational analytical study, 200 singleton pregnant women with a gestational age of 28-42 weeks and cephalic presentation who gave births at the Department of Obstetrics and Gynecology, Sanpasitthiprasong Regional Hospital between September 2018 and March 2019 were recruited. The present study focused on pregnancy with all range of risk (i.e. low risk: term low risk pregnancy, and high risk: preterm pregnancy, pre-pregnancy body mass index (BMI) > 30 kg/m^2, teenage pregnancy, low birth weight, and macrosomia) and those whose physical examination and ultrasonography were performed in the intrapartum period and within 24 hours before delivery. Pregnant women who presented in both latent and active phase of 1st stage of labor with either intact or ruptured membranes were included. We excluded mothers who have conditions that required specific treatment and possibly prevented them from participating in the study. Those with fetal malformation, oligohydramnios, polyhydramnios and other maternal conditions which could affect fundal height and fetal growth; namely, pregnancy induced hypertension, gestational and overt diabetes, and uterine/ovarian tumors were excluded. Oligohydramnios and polyhydramnios were based on antenatal care history and ultrasonographic finding at recruitment. Sample sizes determination was based on a research question "whether there was a difference in the within-10% accuracy between different tools (whether the proportion was different for at least one group)" According to previous literature reporting the within-10% accuracy of 53.5%[15] and 82%[16] for Dare's and Hadlock's equations, a sample size of 172 was required at 95% confidence level and 90% power using the following formula. The sample size was increased to 200 to account for 15% missing data/loss to follow-up.

$$n = \left[\frac{z_{1-\frac{\alpha}{2}}\sqrt{p_{01}+p_{10}} + z_{1-\beta}\sqrt{p_{01}+p_{10}-(p_{01}-p_{10})^2}}{\Delta}\right]^2$$

All pregnant women meeting the above inclusion/exclusion criteria gave written informed consent. This study was approved by the Sanpasitthiprasong Regional Hospital Ethic Committee (055/2561).

Data collection was performed during the intrapartum period. After giving informed consent, participants were questioned about personal and medical history as well as obstetric history including gravid and parity, gestational age (GA) and due date. Data on antenatal care including pre-pregnancy BMI were obtained using medical and antenatal care record reviews by the investigators, NP and PP. BMI was categorized according to the World Health Organization (WHO) Expert Consultation's recommendation on appropriate BMI for Asian populations(17). Weight gain during pregnancy was defined based on pre-pregnancy BMI group(18). Symphysis-height of fundus (SFH) and abdominal girth (AG) were assessed by 2nd year residents using non-stretch tape. The height of uterine fundus was measured from the pubic symphysis to the top of the uterus measure after emptying bladder. Following the widely-used method(19, 20), AG was measured at the level of the umbilicus. Per vaginal examination was carried out by 2nd year obstetric and gynecological (OBGYN) residents and the station of fetal head assessed with reference to ischial spine. After that, ultrasonography was performed by the same residents using Samsung Sonoage R5 following standard protocols. Biparietal diameter (BPD) was measured at the level where both thalami and cavum septum pellucidum were visualized. BPD was measured from inner to outer table of the skull bones. Head circumference was measured in the same plane. Abdominal circumference was measured at the level of bifurcation of the hepatic vein into right and left branches. Femoral length was measured with the femur excluding the femoral head and the epiphysis along the vertical axis seen transversely(21). Ultrasonographic findings at recruitment were also used to exclude women with certain abnormalities described in the above exclusion criteria. For each pregnant woman, all measurements and ultrasonography were performed by one of the 2nd year residents who were trained specifically for this study and every measurement performed in the present study was verified by Maternal Fetal Medicine (MFM) specialist. In case that there was discordance of the measurements between the resident and MFM specialist, results by the MFM specialist were used. After that, the weight of baby was estimated by four different methods: ultrasonography-based Hadlock IV, Dare's, Johnson's, and Buchmann's clinical equations with detailed equations as shown below.

Hadlock IV(21): $\text{Log10 (EFW)} = 1.3596 - 0.00386 * AC * FL + 0.0064 * HC + 0.00061 * BPD * AC + 0.0424 * AC + 0.174 * FL$

Dare's(19): $EFW = SFH\ (cm) * AG\ (cm)$

Johnson's(22): $EFW = 155 * (\text{fundal height (cm)} - x)$

where $x = 11$ at plus station; $= 12$ at zero station;

$= 13$ at minus station

Buchmann's(23): $EFW = (SFH\ (cm) - 5) * 100$

EFW: estimated fetal weight (grams), AC: abdominal circumference (cm), FL: fetal length (cm), HC: head circumference (cm), BPD: biparietal diameter (cm), SFH: Symphysis-height of fundus (cm), AG: abdominal girth (cm)

Actual birth weight of the newborns in grams was measured by registered nurses using Seca 334 Equip Health Care and recorded in a case record form. Low birth weight and macrosomia were defined as actual birth weight of $< 2,500$ and $\geq 4,000$ grams, respectively.

Statistical analyses

All statistical analyses were performed using Stata software version 14.2 (StataCorp LLC, Texas). Data on mother characteristics including personal and obstetric history, physical examination results, and actual birth weight of the newborn were described using number (percentage), mean (standard deviation (SD)), median (interquartile range (IQR)) for categorical, normally - and non-normally distributed continuous variables respectively. Mean birth weight computed by each estimation equation was compared with actual birth weight using the pair t test. Mean absolute error was computed as the average of the absolute difference between actual and estimated fetal birth weight by each estimation method. Mean absolute error percentage was computed as the mean of the product of dividing absolute difference between actual and estimated birth weight by actual birth weight and multiplying by 100. Accuracy within 10% of actual birth weight was computed and compared between two methods using McNemar's test and across four methods using Cochran's Q test. This was performed for all participants and stratified by levels of actual birth weight (< 2,500, 2,500-3,999 and ≥ 4,000 grams) and gestational age at birth (< 37, and ≥ 37 weeks). Ability of the four equations to predict low birth weight and macrosomia was examined and sensitivity, specificity, positive predictive value, negative predictive value, and the area under the receiver operating characteristics curves (AUR) were computed. Comparison in these predictive ability measures was carried out using McNemar's test and non-parametric methods[24]. A p value of < 0.05 was considered statistically significant.

Results

Characteristic of mothers and actual birth weight of the newborns are shown in Table 1. The mean ± SD age of mothers was 26.1 ± 6.3 years, with two-thirds aged between 20 - 34 years. The average pre-pregnancy BMI was 22.0 ± 4.5 kg/m^2, with approximately one-third being over-weight or obese. Most of the pregnant women had never given birth before (55.5%) and the median (IQR) of gestational age was 38 (38-39) weeks. An average actual fetal birth weight ± SD was 3,069.9 ± 464.8 grams and 87 percent weighed within normal birth weight category. Considering high risk groups, 16.5 percent of all participants were teenage pregnancy (age < 20 years old), 18 percent were obese according to pre-pregnancy BMI, 8.5 percent presented with preterm pregnancy and 13 percent were either low birth weight or macrosomia.

Table 2 shows the actual birth weight of newborns and fetal birth weight estimated using four different methods in all participants and by actual birth weight category. The mean ± SD actual birth weight of newborns was 3,069.9 ± 464.8 grams. Overall, the four methods gave different mean ± SD estimation of fetal birth weight, ranging from 2,976.5 ± 447.7 to 3,682.4 ± 499.6 grams. The fetal birth weight estimated by the Buchmann's method was comparable with the average actual birth weight, while those of other three estimation methods were different from the actual values. Considering absolute differences between actual and estimated fetal birth weight, the smallest absolute difference was observed for ultrasound method, while the largest observed for the Johnson's method (absolute difference ± SD of 238.3 ± 213.4 and 654.1 ± 418.8 grams, respectively). However, there was no discrepancy in the absolute difference between the actual birth weight and estimated birth weight obtained form each of the four clinical equations. Ultrasonography had the lowest mean absolute error percentage, followed by Buchmann's method, while highest mean absolute error percentage was observed for Johnson's method. When considering within 10% difference from the actual birth weight, the proportion of having within 10% accuracy differed across four different estimation methods (p < 0.001), with the highest proportion of within-10% accuracy observed for ultrasonography. Similar results were observed for those with low and normal actual birth weight. However, in infants with actual birth weight of ≥ 4,000 grams, the Johnson's and Dare's clinical equations gave more accurate estimations than the Buchman's and ultrasonography methods as indicated by both mean absolute error percentage and within-10% accuracy.

Table 1. Characteristics of participating pregnant women and actual birth weight of the newborns (n = 200).

Characteristics	
Maternal age (years)	26.1 ± 6.3
Maternal age group	
< 20 years	33 (16.5%)
20 - 34 years	143 (71.5%)
≥ 35 years	24 (12%)
Pre-pregnancy BMI (kg/m²)	22.0 ± 4.5
Pre-pregnancy BMI group	
< 18.5 kg/m²	38 (19%)
18.5 - 22.9 kg/m²	103 (51.5%)
23 - 24.9 kg/m²	23 (11.5%)
25 - 29.9 kg/m²	22 (11%)
> 30 kg/m²	14 (7%)
Weight gain (kg)	13.2 ± 5.8
Weight gain category	
Low weight gain	71 (35.5%)
Normal weight gain	61 (30.5%)
Excessive weight gain	68 (34.0%)
Gravida	2 (1-2)
Parity	0 (0-1)
Gestational age (weeks)	38 (38-39)
Gestational age group	
Preterm	17 (8.5%)
Term	183 (91.5%)
Symphysis - fundal Height (cm)	35.4 ± 3.2
Abdominal girth(cm)	139 ± 69.5
Membranes intact	143 (71.5%)
Actual fetal birth weight (grams)	3069.9 ± 464.8
Category of actual birth weight	
< 2,500 grams	20 (10%)
2,500 - 3,499 grams	174 (87%)
≥ 3,500 grams	6 (3%)

Data are presented as mean ± standard deviation, n (%) or median (interquartile range). BMI: body mass index and BMI was categorized according to the WHO Expert Consultation's recommendation on Asian Pacific criteria[17]

Table 2. Accuracy of fetal birth weight estimated by four different methods, overall and by fetal birth weight category.

	Ultrasound	Dare's	Johnson's	Buchmann's	p value
Overall (n = 200): mean ± SD, actual FBW 3,069.9 ± 464.8 gm					
Mean ± SD of estimated FBW	2,976.5 ± 447.7*	3,451.6 ± 578.8*	3,682.4 ± 499.6*	3,032.7 ± 310.5	
Mean absolute error ± SD	238.3 ± 213.4	489.7 ± 405.6	654.1 ± 418.8	320.3 ± 239.3	
Mean absolute error percentage ± SD	7.1 ± 6.5	16.3 ± 14.9	22.3 ± 16.3	10.2 ± 8.6	
Accuracy within 10% of actual birth weight, n (%)	141 (70.5)**	77 (38.5)	49 (24.5)	117 (58.5)	< 0.001
< 2500 gm (n = 20): mean actual FBW 2,233.9 ± 140.4 gm					
Mean ± SD of estimated FBW	2,276.5 ± 295.0	3,058.0 ± 450.9*	3,309.3 ± 390.4*	2,780.0 ± 246.2*	< 0.001
Mean absolute error ± SD	152.8 ± 130.0	824.0 ± 432.5	1,075.4 ± 356.1	546.1 ± 242.1	< 0.001
Mean absolute error percentage ± SD	6.4 ± 5.7	36.9 ± 20.0	48.1 ± 17.1	24.5 ± 12.2	
Accuracy within 10% of actual birth weight, n (%)	14 (70.0)	2 (10.0)	0 (0)	3 (15.0)	< 0.001
2500-3999 gm (n = 174): mean actual FBW 3,129.9 ± 346.4 gm					
Mean ± SD of estimated FBW	3,037.5 ± 383.4*	3,471.2 ± 568.6*	3,706.2 ± 490.6*	3,050.3 ± 303.2*	< 0.001
Mean absolute error ± SD	236.4 ± 208.6	462.1 ± 389.0	621.5 ± 397.6	279.6 ± 212.4	< 0.001
Mean absolute error percentage ± SD	7.0 ± 6.5	14.4 ± 12.4	20.0 ± 13.4	8.3 ± 6.3	0.027
Accuracy within 10% of actual birth weight, n (%)	125 (71.8)	69 (39.7)	44 (25.3)	114 (65.5)	< 0.001
≥ 4000 gm (n = 6): mean actual FBW 4,116.7 ± 129.99 gm					
Mean ± SD of estimated FBW	3,538.5 ± 304.3*	4,197.3 ± 275.6	4,236.7 ± 288.6	3,366.7 ± 163.3*	< 0.001
Mean absolute error ± SD	578.2 ± 275.0	175.0 ± 94.6	195.0 ± 172.0	750 ± 115.9	< 0.001
Mean absolute error percentage ± SD	13.5 ± 6.9	3.7 ± 2.3	4.3 ± 3.9	17.7 ± 2.8	0.484
Accuracy within 10% of actual birth weight, n (%)	0 (0)	4 (66.7)	5 (83.3)	0 (0)	< 0.001

p value for comparison in within 10% accuracy for four estimation methods using Cochran's Q test. FBW: fetal birth weight, SD: standard deviation. *statistically significant difference between actual birth weight and estimated values from each methods using paired t test (p < 0.05)
**statically significant difference in proportion between the best and second-best estimation methods using McNemar's test (p < 0.05)

Table 3 shows the actual fetal birth weight and birth weight estimated using four different methods by category of gestational age at birth. Among the four estimation methods, ultrasonography showed the smallest mean absolute error and mean absolute error percentage and highest proportion of within-10% accuracy. This was similar for both preterm and term infants.

Ability of four estimation methods to predict low, and normal birth weight and macrosomia based on actual birth weight is shown in Table 4. Ultrasonography had the best performance to predict low birth weight, with the sensitivity, specificity and AUR of 75.0 (95% confidence interval 50.9-91.3), 93.9 (89.3-96.9) and 0.84 (0.75-0.94), respectively. Similar findings were observed for prediction of normal fetal birth weight, with ultrasonography showing the highest AUR of 0.76. In the contrary, Dare's and Johnson's equations were better than Buchmann's method at predicting macrosomia (actual birth weight of ≥ 4,000 grams), with the sensitivity, specificity and AUR of 66.7%, 84.5% and 0.76 and 83.3%, 75.3% and 0.79 for Dare's and Johnson's equations, respectively. As ultrasonography did not predict anyone to have birth weight of > 4,000 grams, AUR for ultrasonography could not be computed. In other words, ultrasonography had no ability to discriminate between those with and without macrosomia.

Table 3. Accuracy of fetal birth weight estimated using four different methods by gestational age at birth.

Gestational age	Ultrasonography	Dare	Johnson	Buchmann	p value
Preterm (n = 17): mean ± SD, actual FBW of 2,486.5 ± 373.3 grams					
Mean ± SD of estimated FBW	2,316 ± 340.0	3,096.6 ± 337.7*	3,382.6 ± 465.8*	2,823.5 ± 281.8*	< 0.001
Mean absolute error ± SD	284.8 ± 277.6	732.6 ± 348.1	1,035.6 ± 321.6	484.7 ± 338.7	< 0.001
Mean absolute error percentage ± SD	10.2 ± 8.7	30.5 ± 16.8	42.7 ± 17.6	19.9 ± 15.1	< 0.001
Accuracy within 10% of actual birth weight, n (%)	11 (64.7)	3 (17.6)	0 (0)	4 (23.5)	< 0.001
Term (n = 183): mean ± SD, actual FBW of 3,124.13 ± 435.04 grams					
Mean ± SD of estimated FBW	3,037.8 ± 405.6*	3,484.6 ± 586.0*	3,710.3 ± 494.6*	3,052.2 ± 306.6*	< 0.001
Mean absolute error ± SD	224.0 ± 206. 9	467.2 ± 404.0	618.6 ± 409.7	305.0 ± 223.1	< 0.001
Mean absolute error percentage ± SD	6.8 ± 6.2	15 ± 14.1	20.4 ± 14.9	9.3 ± 7.1	< 0.001
Accuracy within 10% of actual birth weight, n (%)	130 (71.0)	74 (40.4)	49 (26.8)	113 (61.8)	< 0.001

p value for comparison in within 10% accuracy for four estimation methods using Cochran's Q test. FBW: fetal birth weight, SD: standard deviation
*statistically significant difference between actual birth weight and estimated values from each method using paired t test (p < 0.05)
**statically significant difference in proportion between the best and second-best estimation methods using McNemar's test (p < 0.05)

Table 4. Ability of four fetal birth weight estimation methods to predict low, normal and high actual birth weight (n = 200).

	Ultrasonography	Dare's	Johnson's	Buchmann's	p value
Prediction of low birth weight					
Sensitivity	75 .00 (50.90-91.34)	5.00 (0.13-24.87)	0 (0-16.84)	10.00 (1.23-31.70)	
Specificity	93.89 (89.33-96.91)	97.78 (94.41-99.39)	98.89 (96.04-99.87)	98.89 (96.04-99.87)	
Positive predictive value	57.69 (42.17-71.83)	20.00 (2.85-68.04)	0	50.00 (12.96-87.04)	
Negative predictive value	97.13 (94.05-98.64)	90.26 (89.31-91.12)	89.90 (89.76-90.04)	90.82 (89.52-91.97)	
AUR	0.84 (0.75-0.94)	0.51 (0.46-0.56)	0.49 (0.49-0.50)	0.54 (0.48-0.61)	< 0.001
Prediction of normal birth weight					
Sensitivity	93.68 (88.97-96.80)	81.03 (74.41-86.57)	71.26 (63.93-77.86)	97.70 (94.22-99.37)	
Specificity	57.69 (36.92-76.65)	23.08 (8.97-43.65)	19.23 (6.55-39.35)	7.69 (0.95-24.13)	
Positive predictive value	93.68 (90.42-95.88)	87.58 (84.95-89.80)	85.52 (82.72-87.93)	87.63 (86.35-88.81)	
Negative predictive value	57.69 (41.34-72.51)	15.38 (7.79-28.12)	9.09 (4.21-18.53)	33.33 (8.79-72.18)	
AUR	0.76 (0.66-0.86)	0.52 (0.43-0.61)	0.45 (0.37-0.54)	0.53 (0.47-0.58)	< 0.001
Prediction of macrosomia					
Sensitivity	0 (0.00-45.93)	66.67 (22.28-95.67)	83.33 (35.88-99.58)	0 (0.00-45.93)	
Specificity	100.00 (98.12-100.00)	84.54 (78.67-89.32)	75.26 (68.57-81.16)	98.97 (96.33-99.87)	
Positive predictive value	-	11.76 (6.48-20.42)	9.43 (6.32-13.85)	-	
Negative predictive value	97.00 (97.00-97.00)	98.80 (96.35-99.61)	99.32 (96.06-99.89)	96.97 (96.93-97.01)	
AUR	NA*	0.76 (0.55-0.96)	0.79 (0.63-0.96)	0.49 (0.49-0.50)	0.002

Data in the brackets are 95% confidence interval of its predictive measure.
p value for comparison of area under the receiver operating characteristic curve (AUR) across four estimation methods.
*Ultrasonography did not predict anyone to have birth weight of > 4,000 grams, so AUR for ultrasonography could not be computed.

Discussion

In this observational comparative study in contemporary Thai women and their neonates including both low and high-risk pregnancy, the accuracy and predictive ability of four different estimation methods were compared against actual birth weight. In our study had more pre-pregnancy BMI over 23 but it was not affected to measure SFH and AG for estimated fetal birth weight[20]. Overall, ultrasonography-based Hadlock IV method resulted in the highest proportion of within 10% accuracy among all four methods. Similar results were observed for both low and normal birth weight and both term and preterm neonates, except for those with actual birth weight of more than 4,000 gram in which Dare's and Johnson's clinical equations showed the highest within 10% accuracy.

Ultrasonography-based Hadlock equation has been widely used and this equation showed reasonably high within-10% accuracy. Previous studies in low risk pregnancy showed that the within-10% accuracy of Hadlock equation ranged between 65% to 96%[6, 10, 16, 25, 26]. This was consistent with our study, although our estimates of within-10% accuracy sit at the lower end of the range. The reason for this may be the difference in study populations. While previous studies mostly investigated low risk term pregnancy, our study also included high risk pregnancy, (i.e. with 8.5% of preterm and 13% of low birth weight/ macrosomia). A subgroup analysis in our study showed that ultrasonography had low accuracy in infants weighted ≥ 4,000 grams. This may be explained by likely inadequate ultrasonography view to measure AC in large fetus, standardization of measurements and a small sample size in this subgroup. This further suggests that cautious should be taken when using ultrasonography-based Hadlock equation to estimate fetal weight in large fetus.

Clinical equations may be alternative to ultrasonography as many studies showed that they provided comparable accuracy and predictive ability to ultrasonography-based equations in low risk term pregnancy[6, 12, 15, 16, 27]. Similarly, our study found that Buchmann's method and ultrasonography showed similar within-10% accuracy particularly in normal weight and term neonates. Our subgroup analysis suggested that the most accurate fetal weight estimation method may differ in groups with different actual birth weight and gestational age. Therefore, choice of equations used to estimate fetal birth weight shall be made with caution. Of note, a randomized control trial revealed that estimates based on clinical equations were significantly more likely to be within 10% of actual weight than those derived from ultrasonographic estimates and both clinical and ultrasonographic methods showed a similar ability to discriminate normally and abnormally grown fetuses[13]. Take the results of these studies together, clinical equations are adequately accurate in estimating fetal birth weight and likely to be useful in resource-constrained settings where ultrasonography may not be available.

Various measures of predictive ability have an important role in detecting for high risk group in clinical practice. A small number of previous studies examined ability of various estimation methods to predict these high risk conditions and suggested that the positive predictive values of different methods varied greatly across estimation tools, for example, positive predictive value of 55% for Johnson's clinical equation[6], 70% for Dare's equation[6] and 70% for ultrasonography[6] for predicting low birth weight. While these previous studies mostly focused on term low risk pregnancy, our study provided an opportunity to explore the predictive ability in high risk pregnancy. Additionally, our study showed that Dare's and Johnson's methods in particular had the greater predictive values for macrosomia than ultrasonography and they may be useful in case that large fetus is suspected.

However, only few studies examined a comprehensive set of predictive ability measures including sensitivity/specificity, positive/negative predictive values and AUR. Sensitivity/specificity, and positive/negative predictive values are among the most widely accepted measures; however, these measures are trade-off to each other. That is, estimation methods with high sensitivity essentially had low specificity. This underlines the need for measures of predictive ability that account for both sensitivity and specificity, such as AUR and Net Reclassification Improvement. To our knowledge, our study was among the first that reported AUR for prediction of low birth weight and macrosomia. AUR is a measure of discriminatory ability which is a combined measure of sensitivity and specificity[24]. This measure would help distinguish between those who have and do not have a condition of interest, which may be very useful in clinical practice.

The present study was among the first few studies that compared the performance of multiple methods, both clinical equations and ultrasonography-based, to predict actual fetal birth weight in low, and high risk pregnancy groups, using standard measures of predictive ability. However, our study had a number of limitations. First, although this study was among the largest studies to date, the number of newborns in low birth weight and macrosomia categories as well as preterm pregnancy was relatively small and may have impacted the predictive performance of the estimation methods considered in this study. Larger studies in these high risk groups may be needed. Second, ultrasonography, which is an operator-dependent procedure, was undertaken by 2nd year OBGYN that increased maternal pre-pregnancy BMI did not affect to the accuracy of SFH and AG measurements and estimated fetal birth weight[20] Therefore, the measurement biases and their impact on Hadlock's estimation method may be limited. A previous study suggested that fetal birth weight estimated from ultrasonography performed residents correlated well with the actual birth weight, albeit with low sensitivity to detect macrosomia[15]. Furthermore, due to physical examination and subsequence ultrasonography of each participant were performed by the same physician, there was possibility that data obtained from physical examination might influence ultrasonography measurements and estimated fetal birth weight. However, this influence was likely to be limited because parameters form physical examination were only collected and computation of fetal birth weight based on these parameters was done after performing ultrasonography. Therefore, at the time ultrasonography was being performed, no information on fetal birth weight estimated from clinical equations was known to the physicians. Besides, due to unavailability of data from previous literature, we were not able to calculate sample size to address a research question "to examine the ability of these estimation methods to predict low birth weight and macrosomia in Thai pregnant women". Therefore, it is possible that a study may be underpowered to detect the difference between multiple tools in the ability to predict low birth weight/macrosomia. Additionally, all the clinical equations included in this study were developed in western populations; recalibration of these tools may be needed before use in this Thai population. Alternatively, a population-specific clinical equation should be developed and this may be useful in district community hospitals where OBGYN specialists are not always available.

Conclusions

Among four existing clinical equations, ultrasonography-based estimation equation performed the best at predicting actual fetal birth weight regarding within-10% accuracy, sensitivity/specificity and discriminatory ability to predict low and normal birth weight. Dare's and Johnson's equations performed better than Buchmann's method and ultrasonography at predicting macrosomia and may therefore be probably useful when large fetus is suspected in clinical practice.

Potential conflicts of interest

The authors declare no conflicts of interest.

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