

2010

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Sara Nicholas

Washington University School of Medicine in St. Louis

Methodius G. Tuuli

Washington University School of Medicine in St. Louis

Jeffrey Dicke

Washington University School of Medicine in St. Louis

George A. Macones

Washington University School of Medicine in St. Louis

David Stamilio

Washington University School of Medicine in St. Louis

See next page for additional authors

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Recommended Citation

Nicholas, Sara; Tuuli, Methodius G.; Dicke, Jeffrey; Macones, George A.; Stamilio, David; and Odibo, Anthony O., "Estimation of fetal weight in fetuses with abdominal wall defects: Comparison of 2 recent sonographic formulas to the Hadlock formula." *Journal of Ultrasound in Medicine*. 29,7. 1069–1074. (2010).

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Authors

Sara Nicholas, Methodius G. Tuuli, Jeffrey Dicke, George A. Macones, David Stamilio, and Anthony O. Odibo

Estimation of Fetal Weight in Fetuses With Abdominal Wall Defects

Comparison of 2 Recent Sonographic Formulas to the Hadlock Formula

Sara Nicholas, MD, Methodius G. Tuuli, MD, MPH, Jeffrey Dicke, MD, George A. Macones, MD, MSCE, David Stamilio, MD, MSCE, Anthony O. Odibo, MD, MSCE

Objective. Estimation of fetal weight is particularly challenging in fetuses with abdominal wall defects (AWDs). We sought to compare the accuracy and screening efficiency for intrauterine growth restriction (IUGR) of 2 recent sonographic formulas to those of the Hadlock formula (Am J Obstet Gynecol 1985; 151:333–337) in fetuses with AWDs. **Methods.** This was a retrospective cohort study of fetuses with AWDs. Fetuses with sonographically estimated fetal weights (EFWs) within 14 days before delivery were included. Using the individual biometric measurements, EFWs were calculated using the Honarvar (Int J Gynaecol Obstet 2001; 73:15–20; femur length [FL]), Siemer (Ultrasound Obstet Gynecol 2008; 31:397–400; FL, biparietal diameter [BPD], and occipitofrontal diameter), and Hadlock (BPD, head circumference, abdominal circumference, and FL) formulas. The calculated EFWs were adjusted for interval growth between the dates of sonography and delivery using published sonographic fetal growth velocity standards. Accuracy and screening efficiency for IUGR were compared. **Results.** Seventy-six fetuses were included: 53 with gastroschisis and 23 with omphalocele. The median gestational age at delivery was 36.6 weeks (range, 25.0 to 39.0 weeks). The Siemer formula had the lowest mean percentage error (–2.5% [95% confidence interval (CI), –6.2% to +1.2%]) without systematic bias ($P = .182$). The Hadlock formula had the highest precision (random error, 11.4%), sensitivity (91%), and accuracy for predicting IUGR (85% [95% CI, 77% to 94%]). **Conclusions.** None of the 3 sonographic formulas is ideal for estimating fetal weight in fetuses with AWDs. The Siemer formula should be used when accuracy in the absolute EFW is the goal. For the purpose of making the more clinically relevant diagnosis of IUGR, use of the Hadlock formula is justified. **Key words:** abdominal wall defect; estimated fetal weight; intrauterine growth restriction; screening efficiency; sonographic formula.

Abbreviations

AC, abdominal circumference; AWD, abdominal wall defect; BPD, biparietal diameter; BW, birth weight; CI, confidence interval; EFW, estimated fetal weight; FL, femur length; HC, head circumference; IUGR, intrauterine growth restriction; OFD, occipitofrontal diameter

Received December 24, 2009, from the Division of Maternal-Fetal Medicine and Ultrasound, Department of Obstetrics and Gynecology, Washington University School of Medicine, St Louis, Missouri USA. Revision requested January 21, 2010. Revised manuscript accepted for publication February 17, 2010.

Address correspondence to Methodius Tuuli, MD, MPH, Department of Obstetrics and Gynecology Washington University School of Medicine, Campus Box 8064, 4566 Scott Ave, St Louis, MO 63110 USA.
E-mail: tuulim@wudosis.wustl.edu

Sonographic estimation of fetal weight uses formulas that incorporate various biometric measurements, including the biparietal diameter (BPD), occipitofrontal diameter (OFD), head circumference (HC), abdominal circumference (AC), and femur length (FL).¹ In fetuses with abdominal wall defects (AWDs; gastroschisis and omphalocele), abdominal contents, including the stomach, bowel, and liver, may extrude outward through the defect in the anterior abdominal wall. This may result in underestimation of the AC and affect the accuracy of the fetal weight calculation. Because the estimated fetal weight (EFW) is critical for management decisions, including timing of delivery, it is important to determine the combination of biometric measurements that most accurately estimate the fetal weight in these fetuses.

The standard formula of Hadlock et al² incorporates the BPD, HC, AC, and FL to estimate fetal weight. In fetuses with AWDs in which the AC may be underestimated, there is concern that use of this formula underestimates the fetal weight. To circumvent this, sonographic formulas that exclude the AC measurement have been advocated for such fetuses. A formula published by Honarvar et al³ in 2001 uses only the FL measurement to estimate fetal weight but was not specifically designed for fetuses with AWDs. Only 1 published formula (by Siemer et al⁴ in 2008) has been proposed specifically for the estimation of weight in fetuses with AWDs. This formula was derived by stepwise regression in 380 normal preterm fetuses and applied to a group of 97 fetuses with either gastroschisis or omphalocele. The new equation, which uses the FL, BPD, and OFD, showed significantly lower systematic error when compared to other routinely used formulas.⁴ However, the Siemer formula was derived in preterm fetuses, did not take into account interval growth between the sonographic examination and delivery, and has not been independently evaluated. In addition, the comparative ability of these formulas to correctly predict intrauterine growth restriction (IUGR) in fetuses with AWDs has not been examined.

The aim of this study was to compare the accuracy and screening efficiency for IUGR of the Siemer and Honarvar formulas to those of the standard Hadlock formula in fetuses with AWDs.

Materials and Methods

This was a retrospective cohort study using our perinatal database. Approval for the study was obtained from our Institutional Review Board. All singleton fetuses with diagnoses of AWDs from January 1990 to December 2008 were

identified. Gestational ages were confirmed by first- or second-trimester sonography in all cases. Those that had sonographic examinations with measurement of biometric parameters within 14 days of delivery were included in the study. In cases in which fetal growth had been followed serially, only the last examination before delivery was used. Head measurements were from the leading edge to the leading edge for the BPD and from the outer margin to the outer margin for the OFD at the level of the cavum septum pellucidum. The HC was obtained from the BPD and OFD. The AC was measured at the level of the umbilical vein using the antero-posterior and transverse diameters. The FL was measured from the proximal to the distal metaphysis according to the technique described by O'Brien and Queenan.⁵

With the individual biometric measurements, EFWs were calculated using the Honarvar (FL), Siemer (FL, BPD, and OFD), and Hadlock (BPD, HC, AC, and FL) formulas (Table 1).²⁻⁴ The calculated EFWs were then adjusted for interval growth between the dates of sonography and delivery using published sonographic fetal growth velocity standards.⁶ These standards were established by a prospective, longitudinal sonographic study of 274 low-risk pregnancies scanned from 22 weeks' gestation until term, using an organized serial scanning schedule with all measurements performed by a single observer using the same equipment.⁶ Birth weights (BW) were determined shortly after delivery by nursing staff and recorded in patients' charts.

Correlation between the EFWs from each of the different formulas and BWs was determined using the Pearson correlation coefficient and linear regression analysis. The accuracy of each formula was assessed using the mean percentage error ($[(\text{predicted EFW} - \text{BW}) \times 100 / \text{BW}]$).

Table 1. Selected Sonographic Formulas for Estimating Fetal Weight

Formula	Biometric Measurements	Equation
Hadlock	BPD, HC, AC, FL	$\text{Log}_{10}(\text{BW}) = 1.3596 + (0.00061 \times \text{BPD} \times \text{AC}) + (0.424 \times \text{AC}) + (0.174 \times \text{FL}) + (0.0064 \times \text{HC}) - (0.00386 \times \text{AC} \times \text{FL})$
Honarvar	FL	$\text{EFW}(\text{kg}) = 0.042 \text{ FL}^2(\text{cm}) + 0.32\text{FL} - 1.36$
Siemer	BPD, OFD, FL	$\text{EFW} = -145.577 + 23.724 \times \text{FL}^2 + 1.255 \times \text{BPD}^3 + 0.001 \times \text{eOFD} - 0.0000406 \times 10\text{FL} + 1.03 \times \text{eFL}$

e indicates mathematical constant (2.71828 . . .).

To determine the presence and extent of bias (systematic error), the mean percentage errors were compared to 0 using a 1-sample *t* test and to each other using analysis of variance. Precision (random error) was assessed by calculating SDs of the percentage errors. The SDs were compared using the *F* test. The screening efficiency of each formula for IUGR, defined as BW below the 10th percentile for gestational age on the growth curve of Alexander et al,⁷ was assessed by calculating sensitivities, specificities, positive predictive values, negative predictive values, and overall accuracies for predicting IUGR $([\text{sensitivity} + \text{specificity}]/2)$.

Analyses were performed using STATA version 10.0 software (StataCorp, College Station, TX). Tests with $P < .05$ were considered significant.

Results

A total of 76 patients delivered during the study period (January 1990 to December 2008) met inclusion criteria. Of these, 53 (70%) had a diagnosis of gastroschisis, and 23 (30%) had omphalocele. Table 2 shows selected patient characteristics. The mean maternal age \pm SD was 24.0 ± 1.2 years, and 70% (53 of 76) were nulliparous. The median gestational age at delivery was 36.6 weeks (range, 25.0 to 39.0 weeks). The distribution of BWs is shown in Figure 1. The Kolmogorov-Smirnov test confirmed a normal distribution ($P = .66$) with a mean BW of 2513 ± 683 g. The mean interval between the last sonographic estimation of fetal weight and delivery was 6.4 ± 4.1 days.

The EFWs from all 3 formulas significantly correlated with the BWs (Pearson $r = 0.88$ for Hadlock, 0.80 for Honarvar, and 0.81 for Siemer; all $P < .0001$; Table 3). The Hadlock formula

showed the best correlation and accounted for more variability in the BWs than the Honarvar and Siemer formulas (coefficient of determination, $R^2 = 0.77$ versus 0.65 for Honarvar and 0.66 for Siemer). The Siemer formula showed the lowest mean percentage error (-2.5% [95% confidence interval (CI), -6.2% to $+1.2\%$]) with no significant systematic error ($P = .182$). On the other hand, the Hadlock formula significantly underestimated while the Honarvar formula overestimated fetal weights (mean percentage error, -8.1% [95% CI, -11.0% to -5.2%]; $P < .0001$; and $+8.0\%$ [95% CI, $+3.7\%$ to $+12.3\%$]; $P < .001$, respectively).

Because the best formula for sonographic estimation of fetal weight should have both low bias (systematic error) and high precision (measure of random error), we compared formulas for the best mean percentage error and SD combination. Although none of the 3 formulas met the criteria for the ideal formula, the Hadlock formula showed the best bias (-8.1%) and precision (11.4%) combination for our study population.

Results from evaluation of the screening efficiency of each formula for IUGR are shown in Table 4. The Honarvar formula had the highest specificity (98% [95% CI, 90% to 100%]) but also the lowest sensitivity (24% [95% CI, 9% to 45%]) and lowest screening accuracy (61% [95% CI, 52% to 70%]) for IUGR. The standard Hadlock formula was again the best overall-performing formula, showing both the highest sensitivity (91% [95% CI, 71% to 99%]) and screening accuracy (85% [95% CI, 77% to 94%]) for IUGR.

To evaluate whether the accuracy of the formulas was different in lower weight categories, we compared the mean percentage error of each formula at BWs of less than 2500 g to the overall mean percentage error (Table 5). This analysis

Table 2. Characteristics of Pregnancies With AWDs

Parameter	Gastroschisis (n = 53)	Omphalocele (n = 23)	Combined (n = 76)
Maternal age, y	22.0 ± 1.0	28.9 ± 1.3	24.0 ± 1.2
Nulliparous	37 (70)	16 (70)	53 (70)
Gestational age at delivery, wk	37.0 (30.5 to 39.0)	35.4 (25.0 to 39.0)	36.6 (25.0 to 39.0)
Sonography to delivery interval, d	6.7 ± 3.8	5.7 ± 4.6	6.4 ± 4.1
BW, g	2586 ± 557	2345 ± 904	2513 ± 683
Liver outside abdomen	0 (0)	12 (54)	12 (16)
Growth restricted by BW	20 (37.7)	5 (21.7)	25 (32.9)

Values are mean \pm SD, number (percent), and median (range).

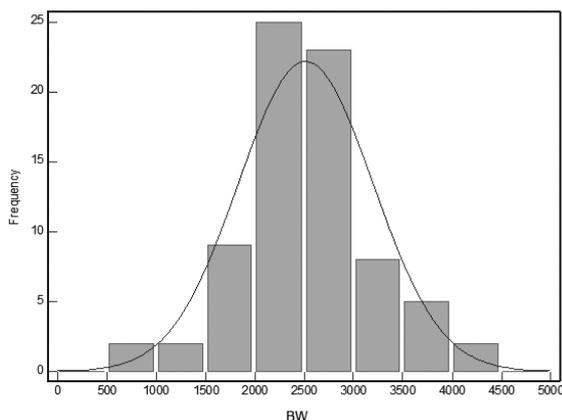


Figure 1. Distribution of BWs of fetuses with AWDs (Kolmogorov-Smirnov test for normal distribution, $P = .66$).

showed that at BWs of less than 2500 g, the Honarvar formula further overestimated fetal weight (mean percentage error, +18.6% compared to +8.0% for all weights; $P < .01$), and the Siemer formula went from no systematic bias to overestimating weight (mean percentage error, +5.9% compared to -2.5% for all weights; $P = .01$), whereas the accuracy of the Hadlock formula remained unchanged or even improved (mean percentage error, -3.4% compared to -8.1% for all weights; $P = .06$).

Discussion

Sonographic estimation of fetal weight is challenged by inaccuracy. Even under ideal measuring circumstances in healthy fetuses, a mean error of 7% to 10% or greater is the norm.⁸ Furthermore, the accuracy varies considerably for the same fetal measurements when different sonographic formulas are used.⁹ These issues are compounded when fetal anomalies such as

AWDs distort biometric measurements. For fetuses with AWDs, attempts to overcome this problem have produced formulas such as the Honarvar and Siemer formulas, which exclude the presumably inaccurate AC measurement. To be useful, such formulas must not only be accurate and precise but, more importantly, correctly distinguish growth-restricted from normally grown fetuses.

In this study, we compared the accuracy of the Honarvar and Siemer formulas to that of the Hadlock formula for estimating fetal weight in fetuses with AWDs. Our results indicate that none of the formulas is ideal in terms of having all of the desired attributes of low bias (systematic error), high precision (random error), and high screening accuracy for IUGR (screening efficiency). The Siemer formula, the only formula proposed specifically for fetuses with AWDs, most accurately estimated fetal weight with no systematic error. The Hadlock formula was most efficient in screening for IUGR, with high sensitivity, specificity, and screening accuracy. Although the screening accuracy of the Siemer formula for IUGR was similar to that of the Hadlock formula (74% versus 85%; $P = .08$), its low sensitivity (64%) makes it a poor screening tool. The Honarvar formula, which also excludes the AC measurement, significantly overestimated fetal weight with low precision. It also showed poor screening efficiency with very low sensitivity (24%) and poor screening accuracy (61%) for IUGR.

The apparent paradoxical performance of the Siemer and Hadlock formulas, in which the Siemer formula is most accurate in estimating weight overall but the Hadlock formula performs better in screening for IUGR, deserves a special comment. We hypothesize that the Hadlock formula “corrects” for the known tendency of sono-

Table 3. Mean Percentage Error (Bias) for EFW, SD (Precision), and Correlation With BW of the 3 Sonographic Formulas in Fetuses With AWDs

Formula	Correlation of EFW With BW			Accuracy for Estimating Fetal Weight		
	Pearson <i>r</i> (95% CI)	<i>P</i>	Coefficient of Determination, <i>R</i> ²	Mean Error (Bias), % (95% CI)	<i>P</i>	SD (Precision)
Hadlock (n = 62) ^a	0.88 (0.80 to 0.92)	<.0001	0.77	-8.1 (-11.0 to -5.2)	<.001	11.4
Honarvar (n = 76)	0.80 (0.71 to 0.87)	<.0001	0.65	+8.0 (+3.7 to +12.3)	<.001	18.8
Siemer (n = 76)	0.81 (0.71 to 0.88)	<.0001	0.66	-2.5 (-6.2 to +1.2)	.182	16.3

^aLimited to fetuses that had abdominal measurements recorded.

Table 4. Screening Efficiency for IUGR of the 3 Sonographic Formulas for EFW in Fetuses With AWDs

Formula	Sensitivity, % (95% CI)	Specificity, % (95% CI)	Positive	Negative	Accuracy, % (95% CI)
			Predictive Value, % (95% CI)	Predictive Value, % (95% CI)	
Hadlock (n = 62) ^a	91 (71 to 99)	80 (64 to 91)	71 (51 to 87)	94 (80 to 99)	85 (77 to 94)
Honarvar (n = 76)	24 (9 to 45)	98 (90 to 100)	86 (42 to 100)	73 (60 to 83)	61 (52 to 70)
Siemer (n = 76)	64 (43 to 82)	84 (71 to 93)	67 (45 to 84)	82 (70 to 92)	74 (63 to 85)

^aLimited to fetuses that had abdominal measurements recorded.

graphic formulas to overestimate fetal weight at the lower extremes of weight¹⁰ by incorporating smaller AC measurements in fetuses with AWDs. This resulted in increased accuracy at the lower fetal weight ranges and improved the screening efficiency for IUGR. This is supported by the observation that at BWs of less than 2500 g, the Honarvar formula further overestimated fetal weight, and the Siemer formula went from no systematic bias to overestimating weight, whereas the accuracy of the Hadlock formula remained unchanged or even improved.

Although several published studies have compared the accuracy of different sonographic formulas for estimating fetal weight in healthy fetuses,⁹⁻¹² only 1 evaluated the accuracy of sonographic formulas specifically in fetuses with AWDs.⁴ In that study, the Siemer formula showed a lower systematic error compared to 4 commonly used formulas, including the Hadlock formula, when applied to fetuses with AWDs. The mean percentage errors and SDs of the Siemer and Hadlock formulas in that study were similar to those in our study (−1.8% [11.7%] and −11.0% [12.1%] versus −2.5% [16.8%] and −8.0% [11.4%], respectively). The screening efficiency of the different formulas for IUGR was not evaluated.

A major strength of our study was the comparison of the 3 formulas not only in terms of their bias and precision but also in terms of their ability to accurately predict IUGR. Comparison of bias and precision alone as in some of the previous studies may be less clinically useful. For example, if one formula estimates fetal weight at the 50th percentile whereas another has it at the 40th percentile, the difference may appear significant but has little bearing on clinical management. In contrast, it would be clinically relevant if one formula identified a fetus as having IUGR (<10th percentile) whereas another identified

the same fetus as appropriate for gestational age because IUGR is a major predictor of adverse neonatal outcomes in fetuses with AWDs.¹³ Second, we adjusted the EFWs for interval growth between the timing of the sonographic examination and the date of delivery. This is important because omitting such an adjustment would result in underestimation of BWs independent of the true performance of the formula. In fact, Mongelli and Gardosi¹⁴ showed that the accuracy of EFWs was improved when interval growth was taken into consideration. Finally, we included gestational ages spanning the entire spectrum of viability. This makes our results more generalizable to most fetuses with AWDs.

Despite these strengths, there were limitations that should be taken into account when interpreting our results. First, whereas our sample size was larger than those of most prior studies involving fetuses with AWDs, it was still relatively small. This may have accounted for the wide CIs in some of our estimates. This also hindered our ability to perform subgroup analysis to evaluate the effect of important variables such as the type of defect and location of the liver on the accuracy of fetal weight estimation by the different formulas. Second, we excluded from the EFW comparison fetuses that did not have AC measurements. It is possible that nonmeasurement of the AC was not random, likely occurring

Table 5. Comparison of the Accuracy of the 3 Sonographic Formulas for All BW Ranges and BW of Less Than 2500 g in Fetuses With AWDs

Formula	Mean Error, %		P
	BW <2500 g (n = 38)	All BW (n = 76)	
Hadlock (n = 62) ^a	−3.4	−8.1	.06
Honarvar (n = 76)	+18.6	+8.0	<.01
Siemer (n = 76)	+5.9	−2.5	.01

^aLimited to fetuses that had abdominal measurements recorded.

more commonly among fetuses with the most distorted abdomens. If this was the case, our analysis would have underestimated the effect of including distorted AC measurements in the calculation of EFW. However, further analysis showed no significant difference in IUGR between fetuses with and without AC measurements (34.9% [22 of 63] versus 23.1% [3 of 13]; $P = .41$). This suggests that the excluded fetuses were probably not significantly different. Third, the sonographic fetal growth velocity standards used to adjust for interval growth were derived from healthy fetuses with no identifiable risks for accelerated or restricted fetal growth.⁵ Because IUGR is common among fetuses with AWDs, the use of normal standards for adjustment may have resulted in some overestimation of fetal weights. That notwithstanding, the observation that the Hadlock formula (which includes the AC) underestimated and the Honarvar formula (which excludes the AC) overestimated fetal weights, as expected, suggests that any “overadjustment” was small. Finally, as a retrospective study, data collection was dependent on the accuracy of coding and imputation of sonographic findings. If this were not the case, the prevalence of AWDs and accuracy of the measurements in our cohort would be invalid. Fortunately, our perinatal database has been well validated in previous studies, and the possibility of misclassification was found to be minimal.^{15–17}

In conclusion, our study confirms that none of the 3 sonographic formulas is ideal for estimating fetal weight in fetuses with AWDs. Development of an improved regression formula for estimating weight specific for fetuses with AWDs is warranted. Until such a formula is available, the Siemer formula should be used when accuracy in the absolute estimate of fetal weight is the goal. For the purpose of making a more clinically relevant diagnosis of IUGR among fetuses with AWDs, continued use of the standard Hadlock formula is justified.

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