Comparison of sonographic fetal weight estimation formulas in patients with preterm premature rupture of membranes

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Abstract

Background: Estimation of fetal weight (EFW) by ultrasound is useful in clinical decision-making. Numerous formulas for EFW have been published but have not been validated in pregnancies complicated by preterm premature rupture of membranes (PPROM). The purpose of this study is to compare the accuracy of EFW formulas in patients with PPRM, and to further evaluate the performance of the most commonly used formula - Hadlock IV.

Methods: A retrospective cohort study of women with singleton gestations and PPRM, admitted to a single tertiary center between 2003-2017 from 22^{0/7}-33^{0/7} (n=565). All women had an EFW within 14 days of delivery by standard biometry (biparietal diameter, head circumference, abdominal circumference and femur length). The accuracy of previously published 21 estimated EFW formulas was assessed by comparing the Pearson correlation with actual birth weight, and calculating the random error, systematic error, proportion of estimates within 10% of birth weight, and Euclidean distance.

Results: The mean gestational was 26.8±2.4 weeks at admission, and 28.2±2.6 weeks at delivery. Most formulas were strongly correlated with actual birth weight ($r>0.9$ for 19/21 formulas). Mean systematic error was -4.30% and mean random error was 14.5%. The highest performing formula, by the highest proportion of estimates and lowest Euclidean distance was Ott (1986), which uses abdominal and head circumferences, and femur length. However, there were minimal difference with all of the first 10 ranking formulas. The Pearson correlation coefficient for the Hadlock IV formula was strong at $r=0.935$ ($p<0.001$), with 319 (56.5%) of measurements falling within 10%, 408 (72.2%) within 15% and 455 (80.5%) within 20% of actual birth weight. This correlation was unaffected by gender ($r=0.936$ for males, $r=0.932$ for females, $p<0.001$ for both) or by amniotic fluid level ($r=0.935$ for mean vertical pocket <2 cm, $r=0.943$ for mean vertical pocket ≥ 2 cm, $p<0.001$ for both).

Conclusions: Most formulas accurately calculated EFW in patients with PPRM, but the Ott (1986) formula ranked highest, thus it may be the preferred formula to use in this population.

Background

Ultrasound is one of the most useful tools for antepartum fetal surveillance. Estimation of fetal weight (EFW) by ultrasound is a key component in antepartum monitoring and management, as a means of assessing fetal growth and overall wellbeing. Yet, since ultrasound became one of the mainstays of obstetrical care, multiple formulas for calculation of EFW have been proposed[1-12]. These formulas use a variation of fetal biometrics, including abdominal circumference (AC), femur length (FL), head circumference (HC), and biparietal diameter (BPD). Many studies have been performed to assess the accuracy of these formulas in specific scenarios including small for gestational age[13], large for gestational age[14, 15], macrosomia[16], fetal gender[17, 18], and multiple gestation[19, 20].

Preterm premature rupture of membranes (PPROM) affects 2-3% of pregnancies[21, 22]. While no one uniform antenatal monitoring protocol exists, management usually includes initial admission to an

obstetrics unit, antibiotic therapy, daily vital signs assessment, and periodic non-stress tests (NST), with or without ultrasound investigations as well[22]. The decision regarding timing and mode of delivery is one based on clinical judgement combining all of these parameters. Ultrasound evaluation and imaging are affected by multiple factors, including the level of amniotic fluid[23, 24]. Whether the same EFW formulas used for general antepartum purposes can also be used in the setting of PPRM is a matter of debate, and previous studies were either limited by sample size or focused on one formula only. Therefore, the primary objective of this study was to evaluate the accuracy of the various sonographic EFW formulas in patients with PPRM.

Methods

Study Design and Participants

This was a retrospective study of women with singleton gestations admitted with PPRM between 22+0/7 and 33+6/7 weeks of gestation to a university-affiliated, tertiary hospital between January 2005 and December 2017. Exclusion criteria included those with acute chorioamnionitis necessitating immediate delivery, and pregnancies with major fetal genetic or structural anomalies. The study was approved by the local institutional review board (approval #145-2018).

Gestational age was determined using the last menstrual period and was confirmed by a first trimester sonogram. Rupture of membranes was determined based on clinical history and at least one supporting physical examination finding (positive ferning test, significant pooling of fluid in the posterior fornix, or positive AmniSure test). According to departmental protocol, women with confirmed PPRM were admitted to the antepartum obstetrical unit until delivery. They received antenatal corticosteroids, antibiotics, and were monitored for signs of intrauterine infection. Vital signs were taken four times daily. Fetal heart rate auscultation was performed twice a day, in addition to a daily NST. Also, in accordance with our protocol, all admitted women with PPRM had a twice weekly ultrasound for biophysical profile (BPP) and umbilical artery pulsatility index (UA PI), as an adjunct measure for fetal well-being. An EFW was performed at admission, and every 14 days until delivery.

Test Methods and Analysis

The accuracy of twenty-one previously published EFW formulas was tested using the following measures:

1. Pearson correlation coefficient (r), which represent the correlation between the EFW and the actual birth weight (BW). The closer R is to 1, the greater the linear correlation between the EFW and BW.
2. Systematic error [$SE = (EFW - BW) / BW * 100$], which reflects the inherent systematic deviation of a given formula from the actual BW.
3. Random error (RE, calculated as the standard deviation of the SE), which reflects the random component of prediction error.

4. Euclidean distance , which represents the geometric average of the SE and RE, expressed as percentages. The smaller the SE and RE are, the smaller the Euclidean distance and thus the more accurate the formula is. This measure was also used to determine the overall ranking of the formulas.
5. Proportion of estimates (POE) within $\pm 10\%$ of birth weight, which reflects the percentage of measurements within $+10\%$ and -10% of the actual BW.
6. For small-for-gestational age (SGA, birthweight<10th percentile for gestational age), we calculated the Kappa statistics, which represents the agreement between measurements. Kappa ranges from (-1) to (+1), and the closer the value of Kappa is to (+1), the better the agreement between the measurements. Birth weight percentiles were determined based on local population growth curves[25].

The primary objective of this study was to evaluate the accuracy of the various sonographic EFW formulas in patients with PPROM. The secondary objective was to further evaluate the performance of the Hadlock IV formula, as it is one of the most commonly formulas used to today.

Statistical analysis was done using the SPSS software (version 25.0, IBM software, Armnok, NY, USA).

Results

Participants

There were 45,943 singleton deliveries at our institution during the study period. Of those, 845 had PPROM prior to 34 weeks of gestation, and 565 women met the inclusion criteria. Demographic data is presented in Table 1. Mean gestational age at admission was 26.8 $\pm$ 2.4 weeks, mean gestational age at delivery was 28.2 $\pm$ 2.6 weeks, and the median time from EFW to delivery was 3 days (Table 1). Of note, 443 (78%) of the sonographic EFW were performed within 7 days of delivery.

Table 1. Demographic data.

Variable	
Gestational age at admission, weeks (mean $\pm$ SD)	26.8 $\pm$ 2.4
Gestational age at delivery, weeks (mean $\pm$ SD)	28.2 $\pm$ 2.6
Sonogram to delivery interval, days (median [range])	3 [0-14]
Birth weight, grams (mean $\pm$ SD)	1,154 $\pm$ 418
Oligohydramnios (MVP<2cm), n(%)	279 (49.4)
Male neonates, n(%)	317 (56.1)

SD - standard deviation, MVP - mean vertical pocket

Test Results

The twenty-one formulas are listed in Table 2, and the comparison between their performance is presented in Table 3. Most formulas had a strong correlation with actual birth weight (19/21 formulas with $r > 0.9$). The strongest correlation was calculated for formulas using both FL and HC in addition to AC, such as Combs[11] ($r = 0.940$), Ott[12] ($r = 0.940$), and Hadlock[1] ($r = 0.936$).

Table 2: Common formulas used for sonographic fetal weight estimation.

Group 1 (AC and FL)		
1	Hadlock et al. (1985)[1]	$=10^{1.304+0.05281(AC)+0.1938(FL)-0.004(AC)(FL)}$
2	Woo et al. (1985) [2]	$=10^{0.59+0.08(AC)+0.28(FL)-0.00716(AC)(FL)}$
3	Warsof et al. (1986)* [3]	$=e^{2.792 + 0.108(FL) + 0.0036(AC)^2 - 0.0027(FL)(AC)}$
Group 2 (AC and BPD)		
4	Vintzileos et al. (1987) [4]	$=10^{1.879+0.0084(BPD)+0.026(AC)}$
5	Warsof et al. (1977) [¶] [5]	$=10^{-1.599 + 0.144(BPD) + 0.032(AC) - 0.000111(BPD)^2(AC)}$
6	Shepard et al. (1982) [¶] [6]	$=10^{-1.7492+0.166(BPD)+0.046(AC)-0.002546(AC)(BPD)}$
7	Jordaan (1983) [¶] [7]	$=10^{-1.1683+0.0377(AC)+0.0950(BPD)-0.0015(BPD)(AC)}$
8	Hadlock et al. (1984) [8]	$=10^{1.1134 + 0.05845(AC) - 0.000604(AC)^2 - 0.007365 (BPD)^2 + 0.000595(BPD)(AC) + 0.1694(BPD)}$
9	Woo et al. (1985) [2]	$=10^{1.63 + 0.16(BPD) + 0.00111(AC)^2 - 0.0000859 (BPD)(AC)^2}$
10	Hsieh at al. (1987) [9]	$=10^{2.1315 + 0.0056541(AC)(BPD) - 0.00015515 (BPD)(AC)^2 + 0.000019782(AC)^3 + 0.052594(BPD)}$
Group 3 (AC and HC (±BPD))		
11	Hadlock et al. (1984) [8]	$=10^{1.182 + 0.0273(HC) + 0.07057(AC) - 0.00063 (AC)^2 - 0.0002184(HC)(AC)}$
12	Jordaan (1983) [7]	$=10^{0.9119+0.488(HC)+0.0824(AC)-0.001599(HC)(AC)}$
13	Jordaan (1983) [7]	$=10^{2.3231 + 0.02904(AC) + 0.0079(HC) - 0.0058(BPD)}$
Group 4 (AC, FL and BPD)		
14	Hadlock et al. (1985) [1]	$=10^{1.335 - 0.0034(AC)(FL) + 0.0316(BPD) + 0.0457(AC) + 0.1623(FL)}$
15	Woo et al. (1985) [2]	$=10^{1.54 + 0.15(BPD) + 0.00111(AC)^2 - 0.0000764(BPD)(AC)^2 + 0.05(FL) - 0.000992(FL)(AC)}$
16	Shinozuka et al. (1987) [10]	$= 0.23966(AC)^2(FL) + 1.6230(BPD)^3$
17	Hsieh at al. (1987) [9]	$=10^{2.7193 + 0.0094962(AC)(BPD) - 0.1432(FL) - 0.00076742(AC)(BPD)^2 + 0.001745(FL)(BPD)^2}$

Group 5 (AC, FL and HC)		
18	Hadlock et al. (1985) [1]	$=10^{1.326 - 0.00326(AC)(FL) + 0.0107(HC) + 0.0438(AC) + 0.158(FL)}$
19	Combs et al. (1993) [11]	$=0.23718(AC)^2 (FL) + 0.03312(HC)^3$
20	Ott et al. (1986) [¶] [12]	$=10^{-2.0661 + 0.04355(HC) + 0.05394(AC) - 0.0008582(HC)(AC) + 1.2594(FL/AC)}$
Group 6 (AC, FL, BPD and HC)		
21	Hadlock et al. (1985) [1]	$=10^{1.3596 + 0.0064(HC) + 0.0424(AC) + 0.174(FL) + 0.00061(BPD)(AC) - 0.00386(AC)(FL)}$

Abdominal circumference (AC), biparietal diameter (BPD), femur diaphysis length (FL) and head circumference (HC) expressed in cm and estimated fetal weight (EFW) expressed in grams, unless stated otherwise. *FL expressed in mm. [¶]EFW expressed in kg.

Table 3: Comparison of twenty-one formulas for fetal weight estimation.

Formula #	Reference	Pearson coefficient (r)	SE (%)	RE (%)	POE<10% (%)	ED (%)	Kappa for SGA	Rank
Group 1 (AC and FL)								
1	Hadlock 1 (1985)	0.928	-2.35	13.27	58.6	13.48	0.380	8
2	Woo (1985)	0.929	-7.98	14.91	44.4	16.91	0.312	14
3	Warsof (1986)	0.913	2.44	15.41	50.6	15.60	0.350	12
Group 2 (AC and BPD)								
4	Vintzileos (1987)	0.923	-0.76	14.08	54.3	14.10	0.292	10
5	Warsof (1977)	0.922	-13.42	12.06	32.6	18.04	0.336	15
6	Shepard (1982)	0.924	-4.90	13.25	54.0	14.13	0.311	11
7	Jordaan (1983)	0.928	14.83	17.21	36.6	22.72	0.091	19
8	Hadlock (1984)	0.925	-4.34	13.17	56.5	13.87	0.318	9
9	Woo (1985)	0.922	-13.66	11.99	30.1	18.18	0.239	16
10	Hsieh (1987)	0.754	-80.15	21.50	0.7	82.98	-0.006	21
Group 3 (AC and HC ($\pm$BPD))								
11	Hadlock (1984)	0.937	-4.69	12.26	56.8	13.13	0.375	3
12	Jordaan (1983)	0.930	13.29	15.17	37.7	20.17	0.230	18
13	Jordaan (1983)	0.927	28.11	24.00	20.2	36.96	0.048	20
Group 4 (AC, FL and BPD)								
14	Hadlock 2 (1985)	0.933	-4.90	12.39	57.7	13.32	0.392	7
15	Woo (1985)	0.925	-10.66	12.24	41.8	16.23	0.351	13
16	Shinozuka (1987)	0.932	0.62	13.09	60.9	13.10	0.302	2
17	Hsieh	0.895	5.14	18.40	46.4	19.10	0.125	17

(1987)								
Group 5 (AC, FL and HC)								
18	Hadlock 3 (1985)	0.936	-5.17	12.16	57.3	13.21	0.392	4
19	Combs (1993)	0.940	3.23	12.85	58.9	13.25	0.373	5
20	Ott (1986)	0.940	0.36	12.42	62.8	12.43	0.440	1
Group 6 (AC, FL, BPD and HC)								
21	Hadlock 4 (1985)	0.935	-5.40	12.17	56.6	13.31	0.420	6

SE - Systemic error; RE - Random error; POE - Proportion of estimations; ED - Euclidean distance; SGA - small for gestational age; AC - abdominal circumference; FL - Femur length; BPD - Biparietal diameter; HC - Head circumference.

The SE ranged from 0.36% (Ott[12]) to -80.15% (Hsieh[9]), with a mean of -4.30%. The RE ranged from 11.99% (Woo[2]) to 24.00% (Jordaan[7]) with a mean of 14.48%. The largest POE<10% was achieved by the Ott[12] formula, with 62.8% of EFW within $\pm 10\%$ of the actual BW. The formula that was the most accurate, by the lowest Euclidean distance, was again that of Ott[12], utilizing AC, FL and HC. Yet, the Euclidean distance of the top 10 ranking formulas differed only slightly from one to another, ranging from 12.43% to 14.10%, indicating they all performed quite similarly. The best agreement between the EFW and actual birthweight with regards to SGA, manifested by the highest Kappa, was achieved by the Ott's formula (0.440)[12] followed by the Hadlock IV formula[1].

The Hadlock IV formula[1] is commonly used in clinical practice and is integrated in most commercially used ultrasound machines. Thus, we chose to analyze its performance in further detail. The Pearson correlation coefficient for the Hadlock IV formula was strong ($r=0.935$, Figure 1). This correlation was not affected by gender ($r=0.932$ for females, $r=0.936$ for males) or by level of amniotic fluid ($r=0.935$ for MVP<2 cm, $r=0.943$ for MVP ≥ 2 cm). A total of 56.5% of EFW fell within the $\pm 10\%$ range of the actual BW, with 72.2% of EFW within the $\pm 15\%$ of the actual BW and 80.5% of EFW within the $\pm 20\%$ margins of the actual BW.

Discussion

In this study, we aimed to evaluate the performance of previously published EFW formulas in pregnancies complicated by PPRM.

We have found that Ott's formula[12] is the most accurate formula, based on the smallest Euclidean Distance and largest POE<10%. Yet, the differences in performance between most formulas, especially the top 10 ranking formulas, were quite negligible. We also found that the commonly used Hadlock IV

formula[1] was relatively accurate, with more than 70% of estimations falling between $\pm 15\%$ of the actual BW, and performs well in the setting of PPRM, regardless of fetal gender or amniotic fluid volume.

One of the earliest studies investigating EFW in pregnancies complicated by PPRM was conducted in 1990 by Valea et al[26]. They compared the accuracy of EFW in low birth weight fetuses, reviewing 86 fetuses with PPRM and 112 fetuses with intact membranes using two different EFW formulas: Shepard[6] which uses BPD and AC, and Rose and McCallum[27], which uses BPD, FL, and mean abdominal diameter. They determined both formulas were equally applicable regardless of membrane status. Toohey[28] and colleagues performed a similar study in 1991, assessing 98 patients with PPRM who had EFW and amniotic fluid index assessments within 48 hours of delivery, compared to 55 patients in preterm labour with intact membranes and normal amniotic fluid indices. Using the Shepard[6] and Hadlock[1] formulas they found that EFW in PPRM is as accurate as those with intact membranes. These studies were both done almost thirty years ago and had small sample sizes. Their accuracy is affected both by the ultrasound machines that were used at that time, and by the fact that very preterm fetuses were not included. A more contemporary study was performed by Esin et al.[23] and found results similar to ours. Nonetheless, the sample size of this study was half of ours, and the mean gestational age at delivery was almost 5 weeks later, affecting the accuracy of the formulas.

Blann and Prien[29] studied a group of 162 women and compared ultrasonographic and clinical EFW before and after amniotomy in laboring women with actual birth weights. They found a significant difference between EFW variance, with -2.5% before amniotomy and -10.5% afterward. Pre-amniotomy AC had the strongest correlation with actual BW, explained by the fact that soft tissue measurement is more likely to be affected by changes in AFV. Of note, they used the Shepard[6] formula, which did not rank among the top ten performing formulas in our study. Additionally, this study was performed while patients were in labor, and it is unclear how a contracting uterus may factor in and affect ultrasound measurements.

Another study[30] examined a large cohort of 820 pregnancies between 22 and 42 weeks of gestational age, and analyzed nine different factors that may affect precision of EFW. These factors included gestational age, maternal BMI, fetal gender, fetal weight, amniotic fluid index, fetal presentation, placental location, time interval between estimation and delivery, and experts vs. less experienced operator. They found that the only factor that had a statistically significant impact was that of time interval between estimation and delivery, with an interval of greater than seven days having a negative impact on estimation. Similarly, other studies also have not shown that amniotic fluid volume plays a pivotal role in EFW[23, 24]. Our findings are in accordance with those studies, as we found that the accuracy of the commonly used Hadlock IV formula was not affected by low amniotic fluid volume.

Our findings have several clinical implications. Some practitioners may choose to change the current formula they are using in the setting of PPRM, as it ranks low among all other formulas. Others may be satisfied to realize that the formulas used by them today performs well enough for their purposes. Our

findings also provide reassurance for practitioners using the Hadlock IV, regardless of fetal gender or level of amniotic fluid.

EFW by an ultrasound poses many research questions such as which one to use, customized growth charts versus population growth charts, growth velocity, factors impacting EFW and more. While our study sheds light on the performance of EFW formulas in a specific setting, additional research is needed to better characterize our use of EFW.

Our study is not free from limitations, mainly its retrospective design. As well, although our mean interval between sonogram to delivery was three days, we included all patients with sonograms up to 14 days from the delivery. Nonetheless, most measurements were done within the seven-day interval from birth, and as can be seen from our results, most formulas performed quite well. Additionally, the size of our cohort and standard management protocol considerably strengthen the findings.

Conclusions

In women with singleton gestation and PPRM, the Ott[12] formula for EFW was the most accurate, yet all of the top ten ranking formulas performed quite well. The commonly used Hadlock IV performed quite similarly to Ott's formula, and is acceptable to use in this specific setting.

Declarations

Ethics approval and consent to participate

The study was approved by the Sunnybrook Health Sciences Centre local institutional review board (approval #145-2018). Informed consent was obtained from all participants. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author Contributions

CW, SR, PQ, EW, AZ, JB, NM, and AA conceptualized and designed the study, and were involved in the acquisition, analysis and interpretation of the data. CW drafted the initial manuscript, and all of the authors reviewed and revised the manuscript critically for important intellectual content. SR and AA were involved in the analysis and interpretation of the data, reviewed the manuscript and provided significant contribution to the revised manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Figures

Figure 1

Correlation between sonographic estimated fetal weight and actual birth weight for the Hadlock IV formula ($r=0.935$).

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