The accuracy of ultrasound estimation of fetal weight in comparison to birth weight: A systematic review

Julia Milner¹ and Jane Arezina²

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Abstract

Ultrasound estimation of fetal weight is a highly influential factor in antenatal management, guiding both the timing and mode of delivery of a pregnancy. Although substantial research has investigated the most accurate ultrasound formula for calculating estimated fetal weight, current evidence indicates significant error levels. The aim of this systematic review was to identify the most accurate method, whilst identifying sources of inaccuracy in order to facilitate recommendations for future practice. Seven studies met the inclusion criteria and 11 different formulae were assessed; ultrasound calculation of fetal weight was most commonly over-estimated. The Hadlock A formula produced the most accurate results, with the lowest levels of random error. Methods incorporating just two measurement parameters were inconsistent, producing large random errors across multiple studies. Key sources of inaccuracy included difficulties obtaining accurate fetal measurements in late gestation; the remainder were operator dependent, including lack of experience and insufficient training and audit. The accuracy of ultrasound estimated fetal weight has improved in the last decade, though a lack of consistency remains evident. National implementation of a rigorous audit programme would likely improve accuracy further, and increase the confidence and clinical value of the method.

Keywords

Ultrasound, estimated fetal weight, birth weight, accuracy

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Introduction

The assessment of fetal growth is a critical component of prenatal care, enabling identification of fetuses at risk of perinatal morbidities or mortality.¹ Recognition of both fetal growth restriction (FGR) and large for gestational age (LGA) fetuses is essential to plan appropriate care.² FGR, referring to fetuses with a birth weight plotting below the 10th percentile, is the single strongest risk factor for stillbirth.³ LGA fetuses, those with a birth weight greater than the 90th percentile,² are at risk of shoulder dystocia and thus increased emergency caesarean section rates.²

Following the introduction of revised FGR management guidelines¹ to reduce stillbirth rates,⁴ ultrasound evaluation of fetal growth has become more widely performed.¹ Amongst other assessments, an ultrasound

growth scan incorporates the performance of three fetal biometry measurements – head circumference (HC), abdominal circumference (AC) and femur length (FL).⁵ Specific standards and landmarks required for each measurement are stipulated by the National Health Service Fetal Anomaly Screening Programme,⁶ to ensure accuracy and reproducibility and reduce both inter- and intra-operator variability. The biparietal diameter (BPD) measurement of the fetal head was previously performed in preference to

¹Rotherham NHS Foundation Trust, Rotherham, UK

²University of Leeds, Leeds, UK

Corresponding author:

Julia Milner, Rotherham NHS Foundation Trust, Moorgate Road, Rotherham S60 2UD, UK.
Email: juliahill1@hotmail.com

the HC, though this practice is now considered outdated in the UK, in accordance with the British Medical Ultrasound Society (BMUS).⁵

Whilst historically the three fetal biometry measurements (HC, AC, FL) taken during the scan were plotted on individual population-based charts,^{5,7-9} the measurements are now combined to calculate an estimated fetal weight (EFW),¹ plotted on a customised growth chart (CGC).¹⁰ The CGC was first introduced into practice over a decade ago, though has become widely utilised during the last 5 years.¹⁰ CGCs are personalised to incorporate maternal constitutional characteristics, including body mass index (BMI) and ethnicity, to predict the optimal fetal growth curve for an individual pregnancy.¹⁰ Consequently, any deviation in growth is likely to represent pathology, rather than physiological variation.¹⁰

Substantial research has investigated the most accurate formula for calculating EFW.¹¹⁻¹³ During recent years, formulae adapted to specific populations, for example twin pregnancies or macrosomic fetuses, and those incorporating three-dimensional (3D) ultrasound imaging have been evaluated, though they are yet to become clinically established.¹³ As such, in current UK clinical practice, the RCOG¹ and BMUS advocate the use of the Hadlock A formula¹⁴; a regression method combining all three measurements.⁵ Although most evidence supports formulae incorporating all three parameters,¹⁵⁻¹⁷ the AC measurement is the most sensitive individual indicator of abnormal fetal growth.^{18,19}

In 2005, a systematic review assessing the accuracy of ultrasound EFW found the Hadlock A formula¹⁴ produced the smallest systematic mean errors on a normal fetal population.¹¹ Whilst this evidence was reinforced more recently,¹² large random error levels persist.^{16,20} Most significantly, calculation of EFW using ultrasound is generally overestimated, especially in the population of small fetuses,^{12,20} raising concerns regarding increasing levels of obstetric intervention.^{21,22} When considering the management of delivery, EFW should be accurate to within 5%, though 10% is considered acceptable,^{11,23} thus minimising random error levels is critical.^{11,15}

The aim of this review was to assess the present accuracy of ultrasound calculation of EFW, identifying the most consistent formula, whilst establishing the key factors currently affecting accuracy.

Method

Study selection criteria

Pre-specified inclusion and exclusion criteria were utilised. Studies published from 2005 onwards were

sought that compared the ultrasound calculation of EFW to the actual birth weight of the neonate, within a 7-day scan to delivery interval, to assess the degree of accuracy. All studies incorporated data from 24 to 42 weeks gestational age at delivery. Study design was not restricted and there was no stipulation of sampling method; both selected and random groups of participants were included. Multi-ethnic studies, performed both within and outside of the UK, were incorporated to enhance the strength and generalisability of the results,^{11,18} providing the method had not been adapted to a specific ethnic population. Studies were excluded that incorporated data from multiple pregnancies and known fetal anomalies, and also those focusing exclusively on specialist equations for FGR and macrosomia.²⁴ There were no restrictions regarding maternal characteristics, including BMI, to ensure the review was representative of a typical population.

Studies were only included if the national screening standards fetal biometry measurements were utilised⁶ and the Hadlock A formula¹⁴ was one of the methods being assessed. Data from other formulae evaluated in the studies was also extracted, though only the methods incorporating the AC measurement and at least one other parameter (HC or FL).

The primary calculations of accuracy sought in each study were mean percentage error, relating to systematic error and standard deviation of error, indicating random error.¹¹ The results extracted from the different formulae were compared to determine the most accurate and reliable method of calculating ultrasound EFW. Additional information regarding possible sources of inaccuracy was also obtained.

Search strategy

In December 2015, four databases were searched; MEDLINE, CINAHL, EMBASE and the Cochrane Library; searches included studies from January 2005 to December 2015, identifying all research published since the previous review.¹¹ In addition, the reference lists from selected relevant papers were reviewed to identify further studies.²⁵

Both subject headings and free text terms were utilised;^{25,26} the search terms were as follows: [ultrasound OR sonograph* OR ultrason*] AND [f*etal weight OR EFW or f*etal biometry] AND [birth weight OR birth-weight] AND accura*. Unpublished studies and grey literature were not included,^{25,26} due to time constraints and practical issues.

A supplementary search was performed in February 2016 to identify any recently published literature; though several new articles were identified, all were subsequently excluded.

Screening and selecting

The articles were screened manually by the reviewer (first author) utilising a data screening tool; the titles and abstracts of the studies were initially assessed, to identify duplicate results and exclude any research that was noticeably irrelevant.^{25,26} Subsequently, full text papers of the remaining eligible studies were obtained and assessed for final inclusion.^{25,26}

A flow chart illustrating the search strategy and reasons for exclusion was produced to preserve the transparency of the review (Figure 1).^{25,26}

Quality assessment

The quality assessment of diagnostic accuracy studies (QUADAS) 2 tool²⁷ was used to assess the quality of the articles for the risk of bias and applicability,^{25,26} considering assessment of sample size, data collection period, number of ultrasound operators and machines, alongside referenced measurement standards and formulae.

Data extraction and synthesis

Data were extracted using a customised Microsoft Excel template, and subsequently imported into Stata statistical package.²⁸ The data were initially analysed collectively and then split into subgroups, facilitating closer comparison of specific formulae. Forest plots were produced to demonstrate the heterogeneity of the results and determine if a meta-analysis was appropriate. The chi-squared test and I^2 statistic were utilised to assess for the presence and degree of heterogeneity.^{25,26}

Additional descriptive data detailing sources of inaccuracy was recorded and synthesised.

Results

Table 1 illustrates the seven studies and associated methods included in the results analysis; in total, 11 different formulae were assessed. Each formula incorporated the AC measurement and at least one

Figure 1. Search strategy flow chart.

Table 1. Studies and formulae included in the review

Study ID	Formula ID	Parameters
1. Mirghani et al. ¹⁸	1a. Hadlock A ¹⁴	H, A, F
	1b. Woo et al. ²⁹	A, F
2. Anderson et al. ³⁰	2a. Hadlock A ¹⁴	H, A, F
	2b. Weiner A ³¹	H, A, F
	2c. Weiner B ³¹	H, A
	2d. Hadlock B ¹⁴	A, F
	2e. Ferrero et al. ³²	A, F
3. Siemer et al. ³³	3a. Hadlock A ¹⁴	H, A, F
	3b. Hadlock B ¹⁴	A, F
4. Melamed et al. ¹⁵	4a. Hadlock A ¹⁴	H, A, F
	4b. Combs et al. ³⁴	H, A, F
	4c. Ott et al. ³⁵	H, A, F
	4d. Hadlock et al. ³⁶	H, A
	4e. Jordaan ³⁷	H, A
	4f. Hadlock ¹⁴	A, F
	4g. Woo et al. ²⁹	A, F
	4h. Warsof et al. ³⁸	A, F
5. Barel et al. ¹⁶	5a. Hadlock A ¹⁴	H, A, F
	5b. Combs et al. ³⁴	H, A, F
	5c. Hadlock B ¹⁴	A, F
	5d. Warsof et al. ³⁸	A, F
	5e. Woo et al. ²⁹	A, F
6. Faschingbauer et al. ³⁹	6a. Hadlock A ¹⁴	H, A, F
	6b. Hadlock B ¹⁴	A, F
7. Rashid ⁴⁰	7a. Hadlock A ¹⁴	H, A, F

Note: The numerical study ID and formula ID assigned in Table 1 correlate throughout the results section. H: head circumference; A: abdominal circumference; F: femur length.

other parameter; all studies included the Hadlock A formula.¹⁴

Overall, the methodological quality of the seven included studies was relatively poor. Only four studies

provided referenced standards for measurement planes,^{16,18,33,39} and just two studies reported the number of ultrasound operators utilised, both exceeded 20, introducing inter-observer variations.^{33,39} Similarly, only three studies discussed the ultrasound equipment utilised;^{18,30,33} just one study used the same piece of equipment throughout,¹⁸ again suggesting a lack of consistency and inducing error. All studies did, however, report their inclusion criteria and detailed the referenced formulae included. Equally, none of the studies made an adjustment for the scan-delivery time discrepancy, reducing the possibility of bias.^{11,20}

Initially, the extracted data for all 11 formulae, mean percentage error (MPE) and standard deviation (SD) of error, were assessed and presented collectively (Figure 2).

The MPE varied from -6.88% (formula 2e) to 22.16% (formula 2c), and in the majority of formulae (68%), the EFW was overestimated. There was a wide range in the levels of random error between formulae, with the SD varying from 7.5% to 17.78% . Formulae 2b and 2c, and 4g and 5e produced the largest levels of both systematic and random error, with MPE ranging from 17.0% to 22.16% , indicating significant overestimation of fetal weight.

Results from most of the formulae (formulae 4a–4f) assessed in Melamed et al.'s study,¹⁵ consistently produced an MPE of less than 5% , though the Hadlock A formula (4a), had the smallest SD of error (7.5%).

Due to the inclusion of differing formulae amongst the studies, a meta-analysis incorporating all results was not appropriate, confirmed in results from the chi-squared and I^2 statistical tests; the chi-squared test produced a p -value of <0.1 and I^2 test result was 50.2% (Figure 2), indicating a moderate degree of statistical heterogeneity.

The results were subsequently broken down into subgroups; the Hadlock A formula was investigated initially, pooling data from all seven studies (Figure 3).

The EFW was overestimated in four studies using the Hadlock A formula. No significant difference was identified in the levels of systematic error between older and more recent studies, though the random error has reduced to below 10% in the most recent four studies. When the results of all seven studies are pooled, the overall effect produces a MPE of 0.14% , indicating a slight tendency to overestimate fetal weight; the SD was 3.5% . Consistent overlap in the level of error was demonstrated between all studies, thus the results were combined in a meta-analysis. Chi-squared produced a p -value of 0.5 and the I^2 result was 0% (Figure 3), indicating that there is no significant statistical heterogeneity within the results, and thus any difference within the results is likely due to chance alone.

Figure 2. Forest plot illustrating mean percentage error, standard deviation and weighting for all formulae.

Data were then subsequently grouped for the formulae that incorporated two parameters, firstly, the three formulae including the HC and AC measurements were assessed (Figure 4).

Results for formula 2c were the least accurate, significantly overestimating fetal weight with a MPE of 22.16%. Formula 4d produced the most accurate results, with MPE of -1.5% and random error of 9.2%. Once again, results from the I^2 statistic (66.1%) and chi-squared test ($p=0.05$) (Figure 4) indicated there was moderate-high statistical heterogeneity within the results.

Formulae incorporating the AC and FL were then assessed; in total six different methods were evaluated (Figure 5).

Results were inconsistent and unreliable, with a frequent overestimation of fetal weight. The formula derived by Woo et al.²⁹ (formulae 1b, 4g and 5e) produced the most inaccurate results, with a MPE ranging from 14.7% to 20.8%, and SD of 10.5% to 14.5%. The most accurate results were produced by the Hadlock B

formula (formulae 2d, 3b, 4f, 5c and 6b); such formula was assessed in five studies and produced mean systematic errors ranging from -4.35% to 7.4% and random errors of 8.8% to 17.78%.

Results from the I^2 statistic (55.3%) and chi-squared test ($p=0.01$) (Figure 5) indicated there was a moderate degree of statistical heterogeneity within the results. When the results were combined, the overall MPE was 6.99%.

Sources of inaccuracy

Six studies provided information regarding possible sources of inaccuracy; three suggested the accuracy of EFW reduced in late gestation, with more difficulties obtaining accurate measurements.^{16,18,39} Sources of error in other studies were operator focused; lack of experience, insufficient training and poor optimisation of the ultrasound image.^{30,33} One study¹⁵ believed inaccuracy was related to the number of parameters incorporated within the formula.

Figure 3. Forest plot illustrating mean percentage error, standard deviation and weighting for Hadlock A formula.

Figure 4. Forest plot illustrating the mean percentage error, standard deviation and weighting of formulae incorporating the head circumference and abdominal circumference parameters.

Figure 5. Forest plot illustrating the mean percentage error, standard deviation and weighting of formulae incorporating the abdominal circumference and femur length parameters.

Discussion

Ultrasound calculation of fetal weight is commonly overestimated in comparison to actual weight.^{16,18,30} Whilst the method is reliable, confidence in the accuracy of the calculation remains hindered by random error,^{30,39} accuracy is primarily related to the formula utilised and number of incorporated biometric parameters.^{15,17}

The Hadlock A formula¹⁴ produced the most consistent mean systematic error and lowest random error across all seven studies (Figure 2). When the results were pooled (Figure 3), the formula produced a MPE within the 5% level of accuracy sought in practice,^{11,23} indicating an improvement in accuracy since the previous review.¹¹ The weighting of the studies was, however, related to the accuracy of the results only, with no consideration of sample size or population characteristics,²⁵ limiting the significance of the results. The most accurate results for such formula were obtained by Rashid,⁴⁰ though this study had the smallest sample size ($n=73$) and data were collected from the Bangladesh population only, reducing the power and generalisability of the results.^{11,18} Nonetheless, it must be considered that babies from such population are constitutionally smaller,¹ thus highlighting the effectiveness of the Hadlock A formula¹⁴ when calculating the EFW of small fetuses, a concern raised in previous research.^{12,20}

The UK study by Anderson et al.,³⁰ produced the highest level of error for the Hadlock A formula.¹⁴ Although the study was published in 2007, the data are old; collected from scans performed in 2000.³⁰ In the last decade, there have been significant developments in both ultrasound equipment and practice,^{5,41} and thus, such results offer a poor representation of current accuracy.³⁰

The accuracy of ultrasound calculation of EFW was highest in the formulae that incorporated all three fetal biometric parameters; underpinning previous literature.^{16,42} Aside from the Hadlock A formula,¹⁴ two other methods were assessed that incorporated all three measurements – Ott et al.³⁵ and Combs et al.³⁴; both produced credible results (Figure 3). Comparable findings were acquired in a previous review¹¹ for the Combs et al.³⁴ formula, however, such method is volumetric rather than the typically used regression equation, and has not been widely assessed, thus the reliability of the method remains indeterminate.^{11,16,42} The Ott et al.³⁵ formula was only assessed in one study within this review,¹⁵ and though the results were promising, previous published literature illustrates significant inconsistency.^{20,43}

Methods incorporating the HC and AC parameters only, performed poorly, with large random errors (Figure 4).^{15,30} The Hadlock et al.³⁶ formula was the

most accurate,¹⁵ though random error levels remained substantially higher than those produced by the Hadlock A formula,¹⁴ echoing previous findings.^{11,20} Calculation of the EFW based on the HC and AC parameters only, is particularly rare in clinical practice, as a reliable FL measurement can normally be obtained throughout the third trimester.⁴⁴

Results for the formulae including just the AC and FL measurements (Figure 5) were extremely inconsistent, somewhat concerning as this method is more frequently used in late gestation, when an accurate measurement of the fetal head is often restricted by its deep position within the maternal pelvis.^{42,45} Most significantly, across the seven included studies, random error levels for all formulae incorporating two parameters were persistently higher than the Hadlock A formula.¹⁴

When considering potential sources of inaccuracy, three studies suggested the accuracy of ultrasound EFW reduced in late gestation, with difficulties obtaining adequate measurements of the fetus.^{16,18,33} This issue has been widely discussed and is evident amongst previous literature,⁴⁵ though more recent studies oppose this principle.^{17,46} Rosati et al.⁴³ and Dimassi et al.¹⁷ believe this source of inaccuracy is relevant when considering the high birth weight population and fetuses with macrosomia; accurate weight prediction is critical in this population to facilitate appropriate intervention in pregnancy to reduce the risk of complications in delivery.^{17,43}

Melamed et al.¹⁵ concluded the accuracy of the calculation was positively related to the number of parameters within the formula, findings supported within wider literature.^{17,20} Conversely, when assessing LGA fetuses specifically, Hoopmann et al.²⁴ and Rosati et al.⁴³ believe the formulae based on the AC measurement only, perform most accurately. Such authors suggest a range of formulae should be utilised in clinical practice, and a specific method should be chosen dependent upon the fetal population being assessed.^{24,43}

The remaining sources of inaccuracy identified were operator focused; lack of experience, insufficient training and audit and poor optimisation of the ultrasound image.^{30,33} Such findings are unsurprising in the current sonography climate; in the UK, poor recruitment and retention of sonographers has resulted in increased employment of agency staff, with little time allocated to uphold audit and training.⁴⁷ Both the United Kingdom Association of Sonographers⁴⁸ and the Royal College of Radiologists,⁴⁹ consider audit a key factor in supporting and retaining skills and development, to enable competent practice and provision of a refined ultrasound service.⁴⁹

None of the studies indicated that image quality influenced the accuracy of ultrasound, a key finding evident in

the previous review performed by Dudley.¹¹ During the last decade there have been substantial technological advancements in ultrasound equipment, and the introduction of both harmonic and compound imaging has proved highly influential on image contrast and resolution, enabling more accurate placement of calipers when performing fetal biometry measurements.⁴¹ In spite of this, the rising levels of obesity within the maternal population must be acknowledged,⁵⁰ as increasing BMI detrimentally affects ultrasound image quality;⁴¹ careful and objective interpretation of ultrasound findings is essential, ensuring appropriate limitations are acknowledged.¹

Limitations

Due to time restrictions, only the first author completed the data analysis and synthesis process, thus the review is susceptible to researcher bias;^{25,26} such effects were minimised by utilising a pre-specified research protocol.^{25,26}

In addition, despite the Hadlock A formula¹⁴ incorporating the HC measurement, the formula was introduced over two decades ago, and thus the standards for the measurement plane are based on old practice and do not conform to current national screening standards;^{5,9} this is a consistent, inherent issue in all seven included studies and wider literature, which must be addressed in future research.

Unfortunately, more recent methods for calculating EFW, including 3D formulae, could not be effectively evaluated; such techniques are still being investigated and thus there is insufficient published research available to systematically assess within the scope of this review.

Conclusion

During the last decade, accuracy of ultrasound calculation of EFW appears to have increased, with recent studies consistently producing random errors below 10%. Accuracy of the calculation is attributable to the incorporated parameters, with the greatest accuracy obtained when utilising all three measurements. In clinical practice, if all three measurements cannot be obtained to the standards stipulated by the national screening committee, it is critical that this is documented on the formal report, to ensure the results can be interpreted with appropriate caution.

The Hadlock A formula remains the most reliable regression method, producing the smallest random errors. Although the volumetric formula by Combs et al. produced promising results, further evaluation is required to determine whether such method is suitable for use in clinical practice.

The most common sources of inaccuracy identified were operator dependent, highlighting

the importance of regular training and audit, fundamental to professional development and maintaining competency.

Ultimately, ultrasound calculation of EFW will always have inherent flaws; minimising the level of random error will undoubtedly improve confidence in the calculation and the clinical value of the method within obstetric management.

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Contributors

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