

Accuracy of Estimated Fetal Weight by Ultrasonog-Raphy Compared to Birth Weight in Fetuses < 2500 g and ≥ 4000 g in a Tertiary Hospital

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Abstract

Background: Early identification of fetuses with abnormal fetal growth and extreme birth weights is essential, as these conditions are associated with increased perinatal morbidity and mortality. **Objective:** To evaluate the accuracy of estimated fetal weight (EFW) obtained by ultrasonography compared with birth weight (BW) in fetuses with EFW < 2500 g and ≥ 4000 g. **Methods:** This retrospective observational study included 98 pregnant women followed at a tertiary hospital. Ultrasound examinations were performed within 14 days before delivery. EFW was calculated using the Hadlock formula and compared with BW. Statistical analyses included Pearson's correlation, linear regression, Bland-Altman agreement, mean absolute error (MAE), mean percentage error (MPE), and categorical agreement. **Results:** A strong correlation was observed between EFW and BW ($r = 0.92$, $p < 0.001$). The mean difference was +60.5 g, with limits of agreement ranging from -488.3 g to +609.3 g. The mean percentage error was 3.3%, and 52% of examinations showed an estimation error within $\pm 10\%$ of actual birth weight. Overall agreement between methods was 90%, and the model explained approximately 85% of BW variability ($R^2 = 0.85$). **Conclusion:** Ultrasonographic estimation of fetal weight showed good agreement with birth weight in fetuses with extreme estimated fetal weights, supporting its use in clinical decision-making. Findings regarding fetuses with EFW ≥ 4000 g should be interpreted cautiously due to the limited number of cases.

Keywords

Obstetric Ultrasound, Fetal Biometry, Maternal Characteristics, Small for Gestational Age, Large for Gestational Age

1. Introduction

The definition of estimated fetal weight below the 10th percentile on obstetric ultrasonography includes fetuses classified as small for gestational age (SGA), as well as those meeting diagnostic criteria for intrauterine growth restriction (IUGR). Conversely, large for gestational age (LGA) refers to fetuses with an estimated fetal weight above the 90th percentile [1]. Historically, a cutoff of 2.500 grams has been used to define low birth weight in newborns [2].

Both groups are associated with an increased risk of adverse neonatal outcomes. This may occur due to birth-related injuries in fetuses classified as LGA or increased perinatal morbidity and mortality in those classified as SGA [1] [3] [4], in both cases, there is also a higher likelihood of increased morbidity later in life [5].

The combination of maternal factors and ultrasonographic parameters at the appropriate gestational age has the potential to predict up to 90% of SGA neonates, including those at risk for adverse outcomes such as prematurity, perinatal hypoxia, hypothermia, and hypo-glycemia. This provides essential data for the development of strategies aimed at improving prenatal care [1].

On the other hand, fetuses classified as LGA are also associated with unfavorable outcomes [10], including shoulder dystocia, operative delivery, neonatal asphyxia, emergency cesarean section, severe perineal lacerations, postpartum hemorrhage, and, later in life, metabolic syndrome [6] [7].

Third-trimester ultrasonographic screening can double the detection rate of fetuses at risk of being SGA or LGA and is best performed at approximately 36 weeks of gestation [1] [5] [8].

Finally, accurate estimation of fetal weight by ultrasonography requires adherence to well-established criteria. For this purpose, the Hadlock-4 formula was used, as described in the ISUOG Practice Guidelines [9]. Both SGA and LGA neonates present an increased risk of morbidity and mortality, making fetal weight estimation essential during prenatal care and delivery planning. Early identification and appropriate monitoring of these conditions may help detect potential complications and enable healthcare professionals to minimize associated risks. Therefore, the aim of this study was to evaluate the accuracy of ultrasonographic estimated fetal weight compared to actual birth weight in fetuses with estimated fetal weight (EFW) < 2500 g and ≥ 4000 g.

2. Methods

2.1. Study Design

This is a retrospective, cross-sectional, observational quantitative study that eval-

uated pregnant women who underwent obstetric ultrasonography for estimated fetal weight (EFW) assessment during the third trimester, within 14 days prior to delivery.

2.2. Study Population

The study population and data collection process are illustrated in **Figure 1**.

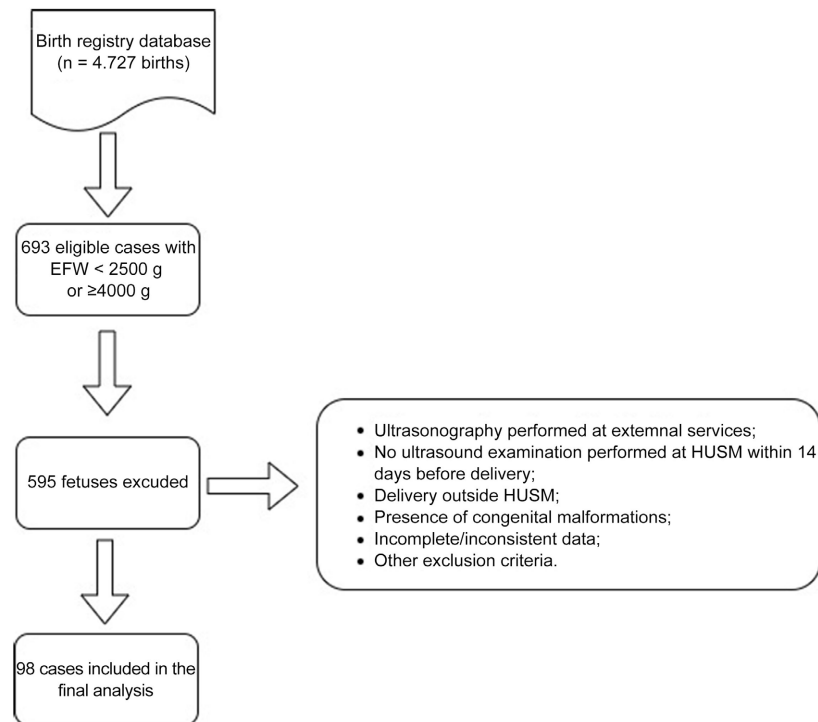


Figure 1. Flow chart of the study population selection process. **Note:** EFW = estimated fetal weight; HUSM = University Hospital of Santa Maria. Exclusion criteria were not mutually exclusive and were therefore not quantified separately.

Patient data were obtained from the database of the project entitled “Evolution and out-comes of pregnancies followed at the University Hospital of Santa Maria (HUSM),” comprising 4.727 births between January 2017 and June 2018, and January 2020 and June 2021.

These data were cross-referenced with the database of the Fetal Medicine Service of HUSM during the same period. Among the 693 eligible cases with estimated fetal weight (EFW) < 2500 g and ≥4000 g, 595 were excluded due to one or more predefined exclusion criteria, including ultrasonography not performed at HUSM within 14 days before delivery, examinations performed at external services, delivery outside HUSM, fetal malformations or chromosomal abnormalities, and incomplete or inconsistent records. Because more than one exclusion criterion could apply to the same patient, these categories were not mutually exclusive and were therefore not quantified separately. These exclusions were necessary to ensure measurement standardization and comparability across examinations. Therefore, 98 patients met the inclusion criteria and constituted the final

study sample.

2.3. Estimation of Fetal Weight and Birth Weight Measurement

Fetal weight was estimated using the Hadlock *et al.* [10] based on ultrasonographic examinations performed with a GE Logiq-P6 device (Gyeonggi, South Korea). The values were compared with gestational age-specific reference intervals derived from established formulas [11].

Ultrasonography is widely used in prenatal care to assess fetal growth and anatomy, allowing the identification of several malformations and abnormalities, particularly during second-trimester screening. To ensure reliable results, examinations should be performed by trained professionals who regularly conduct fetal ultrasound, participate in continuing medical education, follow standardized protocols for abnormal findings, and implement quality control procedures for measurements within the service [9]. Routine ultrasound equipment should provide real-time imaging, adequate resolution and penetration, adjustable acoustic power, image freezing capability, electronic calipers, image storage capacity, and appropriate cleaning protocols. Standardized image acquisition should be performed according to institutional protocols.

Fetal biometry included biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), and femur length (FL), which were used to calculate estimated fetal weight (EFW) [9].

Ultrasound examinations were performed by fetal medicine residents under the supervision of a specialist at the HUSM Fetal Medicine Program, using a GE Logiq-P6 device (Gyeonggi, South Korea) with a 3 - 5 MHz convex transducer. Only cases with EFW < 2500 g or ≥4000 g and delivery within 14 days of the ultrasound examination were included.

BPD was measured in an axial transverse plane of the fetal head, including standard intracranial landmarks such as the falx cerebri, cavum septi pellucidi, thalami, and lateral ventricles. Measurements were taken from the outer edge of the proximal skull table to the inner edge of the distal skull table. HC was calculated from the same axial image using the formula: $HC = (D1 + D2) \times 1.57$, where D1 represents the minor axis and D2 the major axis (occipitofrontal diameter), both measured from the outer skull surfaces. AC was obtained from a transverse abdominal section at the level of the liver, including the umbilical portion of the left portal vein and the fetal stomach. The transverse (D1) and anteroposterior (D2) diameters were measured and converted into an ellipse using the formula: $AC = (D1 + D2) \times 1.57$. FL was measured along the longitudinal axis of the femoral diaphysis, aligning the transducer parallel to the bone and measuring the ossified portion.

Estimated fetal weight was calculated using the Hadlock *et al.* (1985) formula [10], which incorporates BPD, HC, AC, and FL:

$$\begin{aligned} \text{Log}_{10}(\text{EFW}) = & -1.3596 + (0.00061 \times \text{BPD} \times \text{AC}) + (0.0424 \times \text{AC}) \\ & + (0.174 \times \text{FL}) + (0.0064 \times \text{HC}) - (0.00386 \times \text{AC} \times \text{FL}) \end{aligned}$$

At birth, neonatal weight was measured using calibrated digital scales (Fil-

izola BP Baby, São Paulo, Brazil, or Balmak ELP-25BB, Santa Bárbara do Oeste, Brazil), certified by the National Institute of Metrology, Quality and Technology (INMETRO), with regular calibration according to manufacturer recommendations.

2.4. Inclusion and Exclusion Criteria

Inclusion criteria were as follows:

- 1) Singleton live pregnancy;
 - 2) Gestational age determined by last menstrual period and confirmed by first-trimester ultrasound (crown-rump length);
 - 3) Fetuses with estimated fetal weight (EFW) < 2500 g or ≥ 4000 g;
 - 4) Delivery within 14 days of the last ultrasound examination;
 - 5) Delivery performed at HUSM
- Exclusion criteria were:
- 6) Fetal death;
 - 7) Multiple pregnancy;
 - 8) EFW between < 2500 g and 3999 g;
 - 9) Gestational age at birth < 26 weeks;
 - 10) Ultrasound not performed at HUSM;
 - 11) Gestational dating is based on ultrasound after 14 weeks;
 - 12) Presence of fetal malformations or chromosomal abnormalities;
 - 13) Delivery outside HUSM.

2.5. Postnatal Data Collection

The information was collected through the linkage of two databases. The first database originated from the project entitled “Evolution and outcomes of pregnancies followed at the University Hospital of Santa Maria (HUSM),” and the second from the Fetal Medicine Ultrasound Service of HUSM. The patients received care at HUSM either through admission to the Obstetric Center or through prenatal follow-up at the institution. All deliveries occurred at HUSM, which provided the necessary conditions for the implementation of this study.

Postpartum data from all patients were evaluated using a database created through the analysis of medical records from pregnant women and newborns, aiming to assess two birth characteristics: fetal weight and gestational age calculated using the Capurro method.

All fetuses had their estimated fetal weight calculated using the Hadlock *et al.* [10] formula, and analyses were performed by comparing ultrasound-estimated fetal weight (EFW) with neonatal birth weight (BW).

2.6. Statistical Analysis

For sample characterization, mean, standard deviation, minimum and maximum values were used for continuous variables, while absolute and relative frequencies were used for categorical variables. Data normality was assessed using the Kolmogorov-Smirnov test. Pearson’s correlation coefficient was used

to assess the association between ultrasound-estimated fetal weight and birth weight. Linear regression analysis was performed to evaluate explanatory capacity. Agreement and clinical accuracy were evaluated using Bland-Altman analysis, mean absolute error (MAE), mean percentage error (MPE), and the proportion of estimates within $\pm 10\%$ of birth weight. Finally, Bland-Altman plots were used to evaluate the agreement between estimated fetal weight and birth weight. Considering that the residents who performed the evaluations started their residency training in March, stratified analyses were conducted by dividing the evaluations into the months of March, April, and May (higher probability of error) and the remaining months. All analyses were performed using SPSS version 28.0 (Armonk, United States) and MedCalc version 14.8 (Ostend, Belgium).

2.7. Ethical Considerations

The study was approved by the Ethics Committee of the University Hospital of the Federal University of Santa Maria (approval number 5.990.604; CAAE 66664322.4.0000.5346). As this was a retrospective study, a waiver of informed consent was requested, along with a data confidentiality agreement. The risks were considered minimal, and all necessary measures were adopted to ensure the confidentiality and privacy of information obtained from medical records and ultrasound reports.

This research may contribute primarily to the care of high-risk pregnancies by improving the effectiveness of fetal weight estimation methods and identifying maternal or fetal factors that may interfere with these assessments. Accurate fetal weight estimation is relevant for the management of several obstetric complications and may contribute to the evaluation of neonatal survival, thus being important for both society and scientific advancement.

3. Results

The general characteristics of the sample are presented in **Table 1**. Among the 98 included cases, 96 had EFW < 2500 g and 2 had EFW ≥ 4000 g. Because of the very small number of cases in the ≥ 4000 g subgroup, subgroup-specific estimates were interpreted cautiously. Most mothers self-reported white skin color and did not have a completed higher education degree. Maternal age ranged from 14 to 43 years, and gestational age at the time of the measurements ranged from 26 to 40 weeks. The prevalence of alcohol consumption and/or smoking was approximately 20%. Two mothers reported illicit drug use. More than half of the mothers were hypertensive, and slightly more than 15% had diabetes.

Table 2 presents the indicators of the relationship between ultrasound-estimated fetal weight (EFW) and neonatal birth weight (BW). EFW values obtained by ultrasonography were compared with neonatal birth weight to evaluate the accuracy of fetal weight estimation. A strong and statistically significant correlation was observed between the variables. Ultrasound-estimated fetal weight explained

approximately 85% of the variation in birth weight. Adjustment variables contributed little to the model, reinforcing that birth weight prediction can be considered accurate regardless of maternal age and gestational age. The estimates obtained during the first three months ($r = 0.903$; adjusted $\beta = 0.697$; $R^2 = 0.827$) did not differ from those obtained during the remaining months ($r = 0.960$; adjusted $\beta = 0.912$; $R^2 = 0.914$); however, better estimates were observed after the initial months.

Table 1. General characteristics of the sample (n = 98).

	Mean $\pm$ SD	Minimum - Maximum
Birth weight (g)	1916 $\pm$ 656	660 - 4800
Ultrasound-estimated fetal weight (g)	1976 $\pm$ 724	652 - 4900
Margin of error (g)	277 $\pm$ 115	0 - 734
Gestational age (weeks)	34.4 $\pm$ 3.3	26.4 - 39.7
Maternal age (years)	27.6 $\pm$ 7.8	14.0 - 43.0
Number of pregnancies	2.4 $\pm$ 1.6	1 - 10
Fetal weight gain (g)	142.4 $\pm$ 130.7	0 - 510
Variable	n	%
Race/skin color		
White	79	80.6
Black	9	9.2
Brown	10	10.2
Education level		
Incomplete elementary school	20	20.4
Complete elementary school	26	26.5
Complete high school	39	39.8
Complete higher education	5	5.1
Alcohol consumption and/or smoking		
No	80	81.6
Yes	18	18.4
Drug use		
No	96	97.9
Yes	2	2.1
Hypertension		
No	42	42.8
Yes	56	57.2
Diabetes		
No	82	83.7
Yes	16	16.3

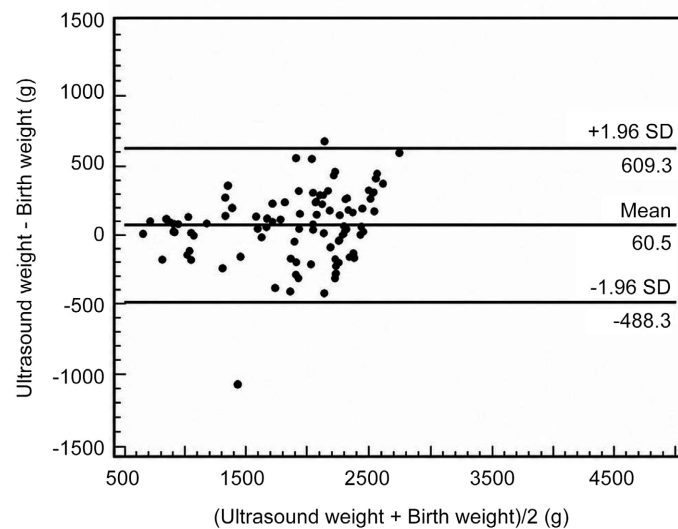
Note: Missing or incomplete data were reported when applicable and excluded from variable-specific analyses. Education level: n = 90 due to missing data. Missing: 8; 8.2%.

Table 2. Correlation and explanatory capacity of ultrasound-estimated fetal weight in relation to birth weight.

Analysis	Measure	Value
Correlation analysis	Correlation coefficient (r)	0.922
	p-value	<0.001
Regression analysis	Crude β (95% CI)	0.836 (0.765 - 0.906)
	p-value	<0.001
	R ²	0.849
	Adjusted β (95% CI)	0.796 (0.706 - 0.885)
	p-value	<0.001
	R ²	0.854

Note: CI = confidence interval; R² = coefficient of determination; adjusted β = adjusted for maternal age and gestational age.

The Bland-Altman plot (**Figure 2**) demonstrates the agreement between ultrasound-estimated fetal weight and birth weight.

**Figure 2.** Agreement between ultrasound-estimated fetal weight and birth weight in grams (Bland-Altman plot). **Note:** SD = standard deviation.

A mean difference of 60.5 g was observed between the two methods, with limits of agreement (margin of error) ranging from -488.3 g to 609.3 g. Regarding categorical agreement (<2500 g or ≥4000 g), both methods classified 90% of the cases within the same category. No differences were observed between the estimates obtained during the first three months of residency training (bias = 60.2 [-536.4; 656.8]) and those obtained during the subsequent months (bias = 61.1 [-366.9; 489.1]) in the agreement analysis.

4. Discussion

Based on the correlation analysis, it was possible to verify that fetal weight esti-

mated by ultrasonography performed within 14 days prior to delivery showed a strong and significant correlation with birth weight, demonstrated good agreement with neonatal birth weight in fetuses with extreme estimated fetal weight. These results are consistent with the study conducted by Ben-Haroush *et al.* [12], which demonstrated that ultrasonographic estimated fetal weight (EFW) is highly correlated with birth weight, further reinforcing that obstetric ultrasonography has become an increasingly established imaging method for this purpose, with the advantage of being a low-cost and widely accessible examination in high-risk services at tertiary hospitals, such as HUSM.

However, the authors emphasize that physicians should be aware of the risk of overestimation in pregnancies with suspected large-for-gestational-age (LGA) fetuses and underestimation in pregnancies complicated by premature rupture of membranes and suspected intrauterine fetal growth restriction.

Correlation analysis was used to assess the strength of association between ultrasound-estimated fetal weight and birth weight [13]. A higher correlation coefficient indicates a stronger linear relationship between estimated and observed values. However, correlation alone does not assess agreement or clinical accuracy, since highly correlated measurements may still present clinically relevant individual differences. For this reason, agreement and clinical agreement were additionally evaluated using Bland-Altman analysis and error-based measures, including mean absolute error (MAE), mean percentage error (MPE), and the proportion of estimates within $\pm 10\%$ of birth weight. These complementary approaches provide a more clinically meaningful interpretation of ultrasonographic performance.

The present study is consistent with much of the literature in supporting that the equation proposed by Hadlock *et al.* remains one of the best options for predicting birth weight, with strong potential for clinical practice [14] [15] in screening for fetal growth abnormalities [10]. Ricci *et al.* [16] highlighted that this formula, when compared with other formulas such as those proposed by Warsof *et al.* and Shepard *et al.*, demonstrated greater predictive accuracy [16]-[18]. In the study conducted by Ricci *et al.* [16], adequate accuracy in fetal weight estimation using the Hadlock *et al.* formula, based on four parameters, was observed, and factors interfering with estimation error included the distance between the maternal skin and uterus, as well as fetal weight itself.

Regarding fetal growth, an expected weight gain of 30 grams per day from the third trimester onward was considered, regardless of the presence of maternal pathology. This may represent a limitation of the present study, since growth-restricted fetuses are expected to gain less intrauterine weight compared to fetuses considered “healthy.” On the other hand, fetuses exposed to hyperglycemic conditions tend to present greater daily weight gain compared to those from non-diabetic mothers.

Furthermore, it was observed that the ability of estimated fetal weight to predict actual birth weight was dependent on gestational age, with a higher rate of accuracy observed during the third trimester of pregnancy. Conversely, there was a

tendency to overestimate estimated fetal weight (EFW) in fetuses weighing more than 4000 g, with a variation exceeding 10% between EFW and actual birth weight. However, the small number of cases in this category does not allow definitive conclusions regarding this finding, which may also be considered a limitation of the present study. The lower accuracy of the Hadlock formula in fetuses with suspected macrosomia may be related to the limitations of conventional two-dimensional biometric measurements, which may not fully reflect soft tissue deposition and overall fetal body composition. In larger fetuses, adipose tissue accumulation and body volume may not be adequately represented by standard parameters such as abdominal circumference, femur length, biparietal diameter, and head circumference, potentially reducing precision in fetal weight estimation. Similar limitations have been reported in previous studies evaluating ultrasonographic fetal weight estimation in macrosomic fetuses. The Bland–Altman limits of agreement also deserve clinical consideration, particularly in fetuses at the extremes of weight. In suspected macrosomic fetuses, an estimation error approaching 600 g may influence obstetric planning and risk assessment. For example, a fetus estimated near the threshold for macrosomia may in practice have a substantially lower or higher birth weight, potentially affecting delivery planning, anticipation of shoulder dystocia, or closer intrapartum monitoring. Therefore, estimated fetal weight should be interpreted together with clinical findings and not used in isolation for obstetric decision-making. Another limitation related to the study design was the absence of blinding of ultrasound measurements displayed on the monitor for the examiner, which may have influenced the obtained values.

Nevertheless, this study may be considered an evaluation of the agreement and accuracy of EFW in clinical practice, since EFW measurements were obtained by several examiners at different stages of training. It was hypothesized that the first three months of fetal medicine residency training could result in discrepancies in the measurements obtained due to the possible inexperience of new residents. However, no differences were observed between the estimates obtained during the first three months and those obtained during the remaining months of the year. This finding suggests that adequate supervision and teaching were provided by the HUSM fetal medicine service throughout the entire training period of future specialists, considering the interval from March to February of the following year.

Furthermore, studies [15] [16] have indicated that there is interobserver variability in estimated fetal weight (EFW) measurements, which may compromise its performance for clinical use. However, this was not observed in the present study, providing evidence that variability in obtaining EFW measurements may be reduced through the standardization of measurement techniques. According to Predanic *et al.*, regarding the learning curve in fetal weight estimation, a significant improvement in accuracy is observed among residents in training after 24 months; however, even among experienced operators, interobserver differences may still occur [19].

According to Ricci *et al.*, an adequate interpretation of fetal growth requires understanding the natural variability of ultrasonographic measurements [16]. The authors also emphasized that operator experience plays an important role in obtaining more accurate fetal weight estimates. The importance of proper training and qualification of obstetric ultrasonography operators should be highlighted in order to ensure the quality and accuracy of fetal weight measurements and estimations [16]. This approach may contribute significantly to successful obstetric follow-up and more informed clinical decision-making. Krispin *et al.* emphasized that ultrasound accuracy mainly depends on fetal presentation, spinal position, and placental location [15].

5. Limitations of the Study

This study has some limitations that should be considered when interpreting the results. First, the retrospective design may introduce selection bias and limit the ability to establish causal relationships. In addition, although strict inclusion and exclusion criteria improved measurement standardization and comparability, they may have reduced external validity and contributed to potential selection bias, particularly considering the reduction from 693 eligible cases to 98 included patients. Second, the relatively small sample size, especially the limited number of fetuses with estimated fetal weight ≥ 4000 g, restricted subgroup analyses and reduced the stability of accuracy estimates for this category. In larger fetuses, the lower accuracy of the Hadlock formula in fetuses with suspected macrosomia may be related to the limitations of conventional two-dimensional biometric measurements, which may not fully reflect soft tissue deposition and overall fetal body composition. In larger fetuses, adipose tissue accumulation and body volume may not be adequately represented by standard parameters such as abdominal circumference, femur length, biparietal diameter, and head circumference, which may contribute to reduced precision in fetal weight estimation.

6. Conclusions

Ultrasound-estimated fetal weight showed good agreement with neonatal birth weight in fetuses with estimated fetal weight (EFW) < 2500 g and ≥ 4000 g. Most ultrasound estimations presented errors within clinically acceptable limits, and more than half of the examinations showed an estimation error within $\pm 10\%$ of actual birth weight. Ultrasound estimated fetal weight also demonstrated good explanatory capacity, explaining approximately 85% of the variation in birth weight. No relevant differences were observed between measurements obtained by examiners at different stages of training. However, findings regarding fetuses with EFW ≥ 4000 g should be interpreted cautiously due to the limited number of cases in this subgroup.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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