# Estimation of fetal weight in pregnancies past term

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Conflict of interest

There are no conflicts of interest in connection with this article.

**Running head**

Ultrasound estimation of fetal weight

**Key message**

A method based on two-dimensional measurements of biparietal diameter and abdominal circumference has good accuracy for predicting birthweight in pregnancies past term.

**Key words**

Ultrasound, prenatal diagnosis, delivery

**Abbreviations**

EFW, estimated fetal weight; BW, birthweight; GA, gestational age; SGA, small for gestational age; FGR, fetal growth restriction, SD, standard deviation; BPD, biparietal diameter; MAD, mean abdominal diameter; AC, abdominal circumference; 2D, two-dimensional; 3D, three-dimensional; FPR, false positive rate; PPV, positive predictive value; NPV, negative predictive value; ROC, receiver operating characteristic; AUC, area under curve; PD, percentage deviation

## Abstract

*Introduction.* The aim of the study was to investigate the accuracy of estimating fetal weight with ultrasound in pregnancies past term, using the eSnurra algorithm.
*Material and methods:* 419 women with pregnancy length 290 days, attending a specialist consultation at Stavanger University Hospital, Norway were included in a prospective observational study. Fetal weight was estimated using biparietal diameter (BPD) and abdominal circumference (AC). The algorithm implemented in an electronic calculation (eSnurra) was used for estimated fetal weight (EFW) calculation. Results were compared with birthweight (BW).
*Results.* The mean interval between the ultrasound examination and birth was two days (SD 1.4). The median difference between BW and EFW was -6 g (CI -40 to +25 g) and the median percentage error was -0.1% (95% CI -1.0% to 0.6%). The median absolute difference was 190 g (95% CI 170 to 207 g). The BW was within 10% of EFW in 83% (95% CI 79% to 87%) of cases and within 15% of EFW in 94% (95% CI 92% to 96%) of cases. Limits of agreement (95%) were from -553 g to +556 g. Using 5% false positive rates, the sensitivity in detecting macrosomic and small for gestational age fetuses were 54 (95% CI 35-72) and 49 (95% CI 49 (35-63), respectively. *Conclusion:* The accuracy of fetal weight estimation was good. Clinicians should be aware of limitations related to prediction at the upper and lower end and the importance of choosing appropriate cut-off levels.

## Introduction

The estimated date of delivery is conventionally at pregnancy day 280, calculated from the first day of the last menstrual period, however, studies have shown that the median pregnancy length is 283 days (1, 2). Pregnancies are considered post-term after 294 days, and reliable dating is a prerequisite for optimal managing of pregnancies past term (3, 4). Increased risks of perinatal morbidity and mortality past term have been described (5, 6). In Norway, an obstetric consultation one week past term is recommended, in which special attention should be paid to detect possibly growth-restricted fetuses (7).

Fetal weight estimation by ultrasound may be challenging, and several growth curves and estimation algorithms/models have been published (8-13). In most models, estimated fetal weight (EFW) is based on two-dimensional (2D) measurements of the fetal head and abdomen, sometimes also including the femur length. All such models have been found to be less accurate for prediction of actual birthweight (BW) when the extreme range of weights are concerned (14, 15). A recent study concluded that current accuracy of EFW with conventional ultrasound parameters had reached its limits (16).

For clinical decisions, cut-off values must be applied to EFW. For instance, macrosomia is often defined as birthweight >4500 g and is associated with increased risk of complications during delivery (17). Fetal growth restriction (FGR) is associated with increased risk of intrauterine death beyond term (18), but it may be challenging to differentiate between FGR and small-for-gestational age (SGA) ante partum (19). The aim of this study was to investigate the accuracy of estimating fetal weight with ultrasound in pregnancies past term, using the eSnurra algorithm. The eSnurra algorithm is a fully population-based model that, in contrast to standard weight prediction models, incorporates gestational age as a central variable.

## Material and methods

Stavanger University Hospital serves a population of approximately 320 000 people and is the only maternity unit in the region. From July 2011, the Norwegian Directorate of Health has recommended a consultation in specialist health care at around 290 day's pregnancy, followed by induction of labor in women with maternal or fetal risk factors (7). From August 2011 to March 2012, 421 women still undelivered at day 290 attended the consultation at the outpatient ward. Out of these, 419 delivered within one week and were included in a prospective observational study comparing EFW and BW. This study was part of a quality assurance study investigating the outcome of a more liberal approach towards induction of labour in prolonged pregnancy (20). All women gave written consent and the Regional Ethics Committee considered the study as a quality assurance study (REK West 2012/485).

An ultrasound examination with estimation of fetal weight was done at day 290. Fetal weight was estimated using biparietal diameter (BPD) and mean abdominal diameter (MAD) (8). MAD was converted to abdominal circumference (AC) using the formula; $AC = \pi * MAD$ . The mean of three measurements was used for calculations and the algorithm implemented in eSnurra (21) was used for fetal weight estimation. The birthweight was obtained immediately after birth.

The ultrasound prediction system computes an estimated percentage deviation (PD), which indicates how much EFW, at a given day of pregnancy, deviates from the population median BW at that same day, measured in percent (21). The relationship between PD and EFW at any given day of pregnancy is thus PD = (EFW – median BW)/median BW × 100%. Fetuses are classified SGA and thus considered at risk, if the EFW falls below the $10^{th}$ population percentile of birthweight; this corresponds to an estimated PD below -14%, i.e. an EFW that is smaller than 0.86 × median BW at that age.

*Statistical analyses*

The predictive quality of the EFW was assessed in several ways. We computed the standard limits of agreement as two times the standard deviation of BW-EFW (22). We then performed a non-linear regression of BW on EFW to detect possible over- or underestimation of BW over the range of EFW. The regression was performed using a Generalized Additive Model from the mgcv package in the R-software (23). To assess relative error, we looked at the distribution of percentage error, calculated as (BW − EFW)/EFW × 100.

By assuming that the PD remains relatively constant for a fetus over a short time span, we computed both the EFW at the day of the ultrasound examination, and an updated EFW value at the day of birth, by combining the estimated PD with the population median BW at the time of examination and of birth, respectively. This is sometimes referred to as the gestation-adjusted prediction method(24).

All our test evaluations were performed for the EFW calculated at the day of birth. We wanted to assess the model's ability to predict particularly high or low birth weights, by looking at macrosomic (BW > 4500g), SGA (BW < $10^{th}$ population percentile), very small (BW < $2.5^{th}$ percentile) and large (BW > $90^{th}$ percentile) fetuses. It may seem reasonable to predict these outcomes by setting the same cut-offs for EFW, i.e. predict a macrosomic fetus when EFW > 4500 g. However, this might not be optimal since – in any regression model – the distribution of EFW is almost always more narrow than the distribution of BW, which in turn leads to low test sensitivity. Accordingly, we also determined the cut-off values for EFW needed to obtain a false positive rate (FPR) of 5% in all tests, and analyzed the results in cross-classification tables. In addition, we evaluated the receiver operating characteristics (ROC) curves, which show the balance between sensitivity and FPR, depending on chosen test cut-off. All confidence intervals have a 95% coverage. Statistical analyses were performed using IBM SPSS Statistics for Windows, v. 22.0, Armonk, NY, USA (IBM Corp.), and the R statistical software version 3.2.0 (25).

## Results

Mean time interval from fetal weight estimation to delivery was two days (SD 1.4); range 0-7, and 74% of the women delivered within two days. Characteristics of the study population are presented in Table 1. Figure 1 shows the relationship between original EFW (at the day of the ultrasound examination) and the updated EFW (at the day of birth). The mean increase from original EFW to updated EFW was 44 grams. The mean difference between BW and EFW was 2 g (CI -25 to +29 g), the median was -6 g (CI -40 to +25 g), the median percentage error was -0.1% (CI -1.0% to 0.6%) and the range was -874 to +973 g. Standard error of the difference was 283 g (CI 262 to 302), and the median absolute difference was 190 g (CI 170 to 207). Limits of agreement were from -553 g to +556 g.

Figure 2 shows the regression of BW on EFW, with 95% CI for the regression line, and limits of agreement. The mean percentage error was 0.2% (CI -0.5% to +0.9%), the median was -0.1% (CI -1.0% to +0.6%), the standard deviation was 7.6% (CI 7.0 to 8.2), the median absolute percentage error was 5.0% (CI 4.5 to 5.6), and the range was -20% to 28%. The EFW was within 10% of the actual BW in 83% (CI 79% - 87%) of cases and within 15% in 94% (CI 92% - 96%) of cases. Figure 3 shows the distribution of percentage error.

Table 2 shows cross-classifications of test values and true outcomes when predicting SGA fetuses (below the 2.5$^{th}$ and 10$^{th}$ percentiles), macrosomic fetuses (more than 4500 grams), and fetuses above the 90$^{th}$ percentile. Table 3 presents the corresponding test characteristics in terms of sensitivity, FPR, positive predictive value (PPV), negative predictive value (NPV), and area under ROC curve (AUC). Figure 4 shows the corresponding test ROC curves.

## Discussion

The main finding in this study was a high accuracy of the algorithm implemented in the eSnurra program, using 2D ultrasound measurements of BPD and AC. In all, 83% of the BW registrations were within ±10% of the EFW, and there was a negligible mean bias. The antenatal prediction of macrosomic children and SGA children is challenging, but the tests achieve high AUC values, with sensitivity around 50% when FPR was set to 5%.

Strengths of the study are a prospective design with thorough quality assurance of data collection, ultrasound examinations performed by trained midwives and obstetricians using ultrasound in daily routine work, inclusion of more than 400 women past term and that more than 70% of the women delivered within two days after the ultrasound examination. A weakness of the study is the limited number of birth weights in the extreme categories, leading to wide confidence intervals in the assessment of test properties in Table 3.

The eSnurra weight prediction system differs from traditional prediction formulas. First, it incorporates gestational age (GA) as a central variable in the calculations. eSnurra computes how much the measured BPD and AC values deviate from their values expected at the current GA. It then translates the BPD and AC deviations into a deviation of EFW from median BW at the relevant GA. This makes effective use of GA in the predictions and follows the gestation-adjusted prediction principle that allows updating the prediction over the weeks following the ultrasound examination (24). Second, the central use of GA in the predictions avoids an extrapolation needed with the traditional formulas; while formulas such as Combs (13) and Hadlock (9) are developed on mostly term births, they are frequently applied for predictions as early as weeks 20-24, a region where they do not necessarily fit. Third, traditional formulas are typically derived from relatively small clinical materials and then applied to completely different populations during actual clinical use. In contrast, eSnurra was constructed from a population-based Norwegian clinical database comprising approximately 40000 ultrasound examinations, and is thus adapted directly to the population to which it is applied. As a consequence, it avoids biases caused by population differences, and its predictive quality can be assessed from the population material on which it was developed (21).

Because the prediction model provides a percentage deviation, it is straightforward to update the EFW from the day of the ultrasound examination to the day of birth. Since there was an average increase in EFW of 44 grams over the time interval from examination to birth, using the original EFW to predict BW would lead to a slight average bias and probably impact the prediction of small and large fetuses. Accordingly, the updated EFW based on the number of days between examination and birth should preferably be used (21). The use of gestation-adjusted prediction might be beneficial allowing clinicians to use updated predictions (24).

Scioscia et al. performed a critical appraisal of the accuracy of EFW by 2D sonography (15). They investigated 29 different formulae and included 441 women who delivered within 24 hours. They found that the percentage of EFW calculations that were within 10% of BW was 69%, and 15% absolute error was 87%. Only two of the algorithms had 10% absolute error >80% and four had 15% absolute error >90%. Our results with 83% and 94% within 10% and 15% absolute error, respectively, demonstrate good accuracy. Kehl et al. studied 628 singleton pregnancies at term and concluded that a good sonographic formula should show no systematic error, an SD of about 7% and inclusion of 80% of cases within a discrepancy level of 10% (16). The eSnurra algorithm conforms to all these criteria, according to our results.

In clinical practice it is important to predict both high and low BW accurately, because clinical decisions are based on cut-off levels. Sovio et al. found that universal scanning compared to selective scanning in the third trimester increased detection rate of SGA from 20% to 57%, but the false positive rate increased from 2% to 10% (26). Karlsen et al. added conditional growth centiles to standard centiles in detecting other adverse fetal outcome and improved the false positive rate from 22% to 6%, but the sensitivity was lower (60% vs. 39%) (27). Comparing studies would be easier if sensitivity was presented at a fixed false positive rate.

A reliable prediction of EFW at high and low cut-off levels is challenging, as shown in Table 3, where the test characteristics of the tails of the weight distribution are presented. Limitations of algorithms are published in other studies (15, 16, 28), and recently highlighted as a problem in Up-to-Date (29). In large fetuses, the distance from the transducer to the distal part of the fetus is large, ultrasound artefacts are enhanced and the boundaries unclear. Oligohydramnios, reducing the image quality, is common in growth-restricted fetuses and in pregnancies past term. It should be stressed, however, that the straightforward approach of applying the same cut-off to EFW in the test as to BW in the target, e.g. to test for macrosomia by an EFW > 4500 grams, is not necessarily optimal in terms of achieved balance between sensitivity and false positive rate. It is seen from Table 3 that in some situations, in particular when testing for BW < 2.5th percentile, a considerably improved sensitivity can be achieved if a somewhat increased FGR is tolerated.

Figure 2 illustrates the association between BW and EFW. The figure shows a slight tendency of the model to underestimate at low weights and overestimate at high weights. While the difference is statistically significant, it reaches clinical relevance only at the extreme ends of the prediction region, where a lack of data makes the conclusion less tenable. The difference might conceivably be due to slightly larger measurement variability in the test population than in the original model development population. It is important to educate all sonographers and continuously assure quality of measurement results. We agree in Dudley's conclusion; efforts should be achieved through averaging multiple measurements, focus on image quality, calibration of ultrasound devices and acknowledge that there is a long learning curve (28).

In a recently published study, ultrasound was found to overestimate the prevalence of large-for-gestational-age fetuses in women with gestational diabetes mellitus (30). Lee et al. suggest that the precision of EFW can be improved by combining 3D limb volume measurements with conventional 2D methods (31). Lindell et al. compared a model combining 2D and 3D measurements with conventional 2D formulas in predicting macrosomic children and found 92% of the EWF calculations to be within 10% absolute error (32). However, the study was performed on a selected population with a high risk of large fetuses, and one examiner performed all the ultrasound examinations. 3D techniques require especially skilled operators and are time-consuming (33), but the combination of 2D and 3D measurements seems promising in high-risk groups.

In conclusion, we found good accuracy of the EWF algorithm based on conventional measurements of BPD and AC implemented in the eSnurra algorithm.

Clinicians should be aware of limitations related to prediction at the upper and lower end and the importance of choosing appropriate cut-off levels.

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**Table 1** Characteristics of study population (n=419)

| | |
|---|---|
| Maternal age (years), median (range) | 29 (17-44) |
| Pre-pregnant BMI (weight/height$^2$), median (range) | 24 (16-41) |
| Nulliparous, n (%) | 212 (50.6) |
| Sex (male), n (%) | 220 (52.5) |
| Breech presentation, n (%) | 3 (0.7) |
| Estimated fetal weight (g) | |
| Mean (SD) | 3757 (383) |
| Median (range) | 3755 (2796-5254) |
| Birthweight (g) | |
| Mean (SD) | 3801 (431) |
| Median (range) | 3780 (2655 – 5180) |

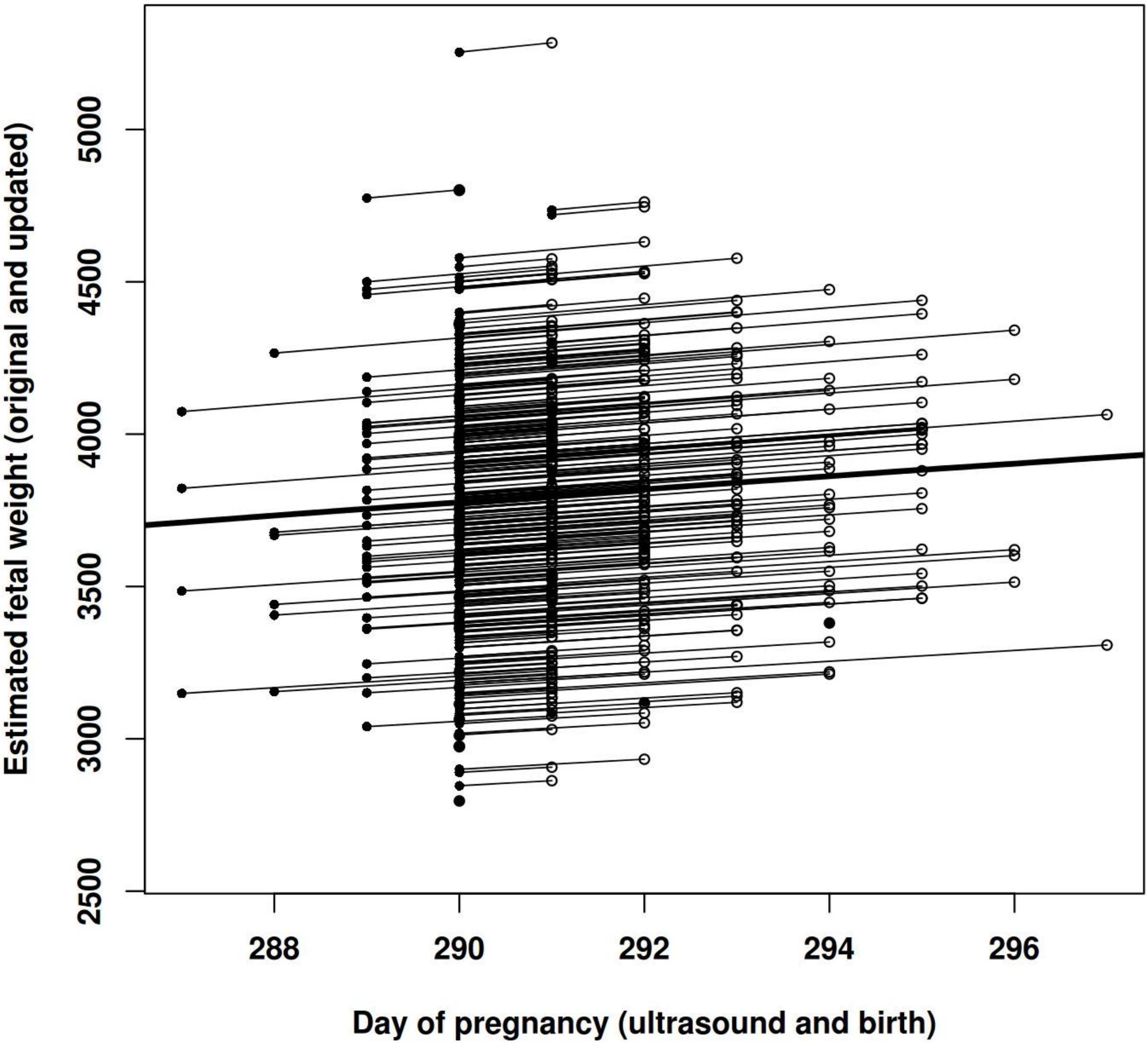
**Table 2** The number of pregnancies cross-classified according to test result and actual outcome. The two upper rows show results when the test cut-off for EFW is the same as the target cut-off for BW. The two lower rows show the corresponding results, when test cut-off for EFW is adjusted to obtain an FPR of approximately 5%.

| | | Prediction target | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | < 2.5th percentile | | < 10th percentile | | > 90th percentile | | > 4500 grams | |
| | Test result | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Test same as prediction target | 0 | 402 | 13 | 350 | 23 | 381 | 18 | 385 | 16 |
| | 1 | 3 | 1 | 22 | 24 | 7 | 13 | 10 | 8 |
| Test adjusted to FPR = 5% | 0 | 385 | 6 | 354 | 24 | 370 | 9 | 375 | 11 |
| | 1 | 20 | 8 | 18 | 23 | 18 | 22 | 20 | 13 |

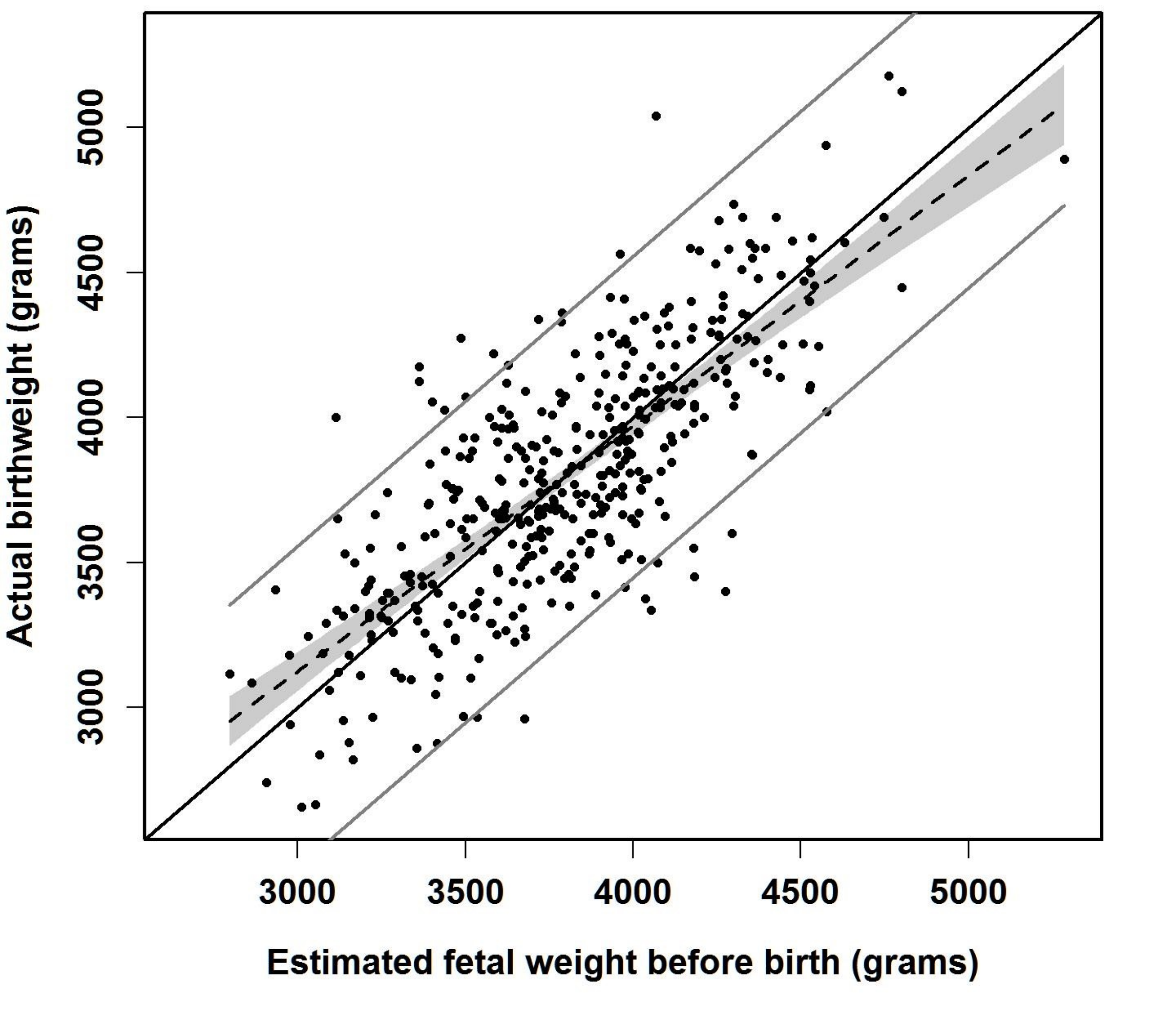
**Table 3** Test characteristics of fetal weight estimation with ultrasound in predicting birth weight

| Prediction target | Test criterion | Sensitivity % (95% CI) | FPR % % (95% CI) | PPV % % (95% CI) | NPV % % (95% CI) | AUC |
|---|---|---|---|---|---|---|
| BW < 2.5th percentile | EFW < 2.5th percentile | 7 ( 1-31) | 1 (0-2) | 25 (5-70) | 97 (95-98) | 0.90 |
| | EFW < 7.1th percentile | 57 (33-79) | 5 (3-8) | 29 (15-47) | 98 (97-99) | |
| BW < 10th percentile | EFW < 10th percentile | 51 (37-65) | 6 (4-9) | 52 (38-66) | 94 (91-96) | 0.92 |
| | EFW < 9.6th percentile | 49 (35-63) | 5 (3-8) | 56 (41-70) | 94 (91-96) | |
| BW > 90th percentile | EFW > 90th percentile | 42 (26-59) | 2 (1-4) | 65 (43-82) | 95 (93-97) | 0.95 |
| | EFW > 84.4th percentile | 71 (53-84) | 5 (3-7) | 55 (40-69) | 98 (96-99) | |
| BW > 4500 g | EFW > 4500 g | 33 (18-53) | 3 (1-5) | 44 (25-66) | 96 (94-98) | 0.94 |
| | EFW > 4350 g | 54 (35-72) | 5 (3-8) | 39 (25-56) | 97 (95-98) | |

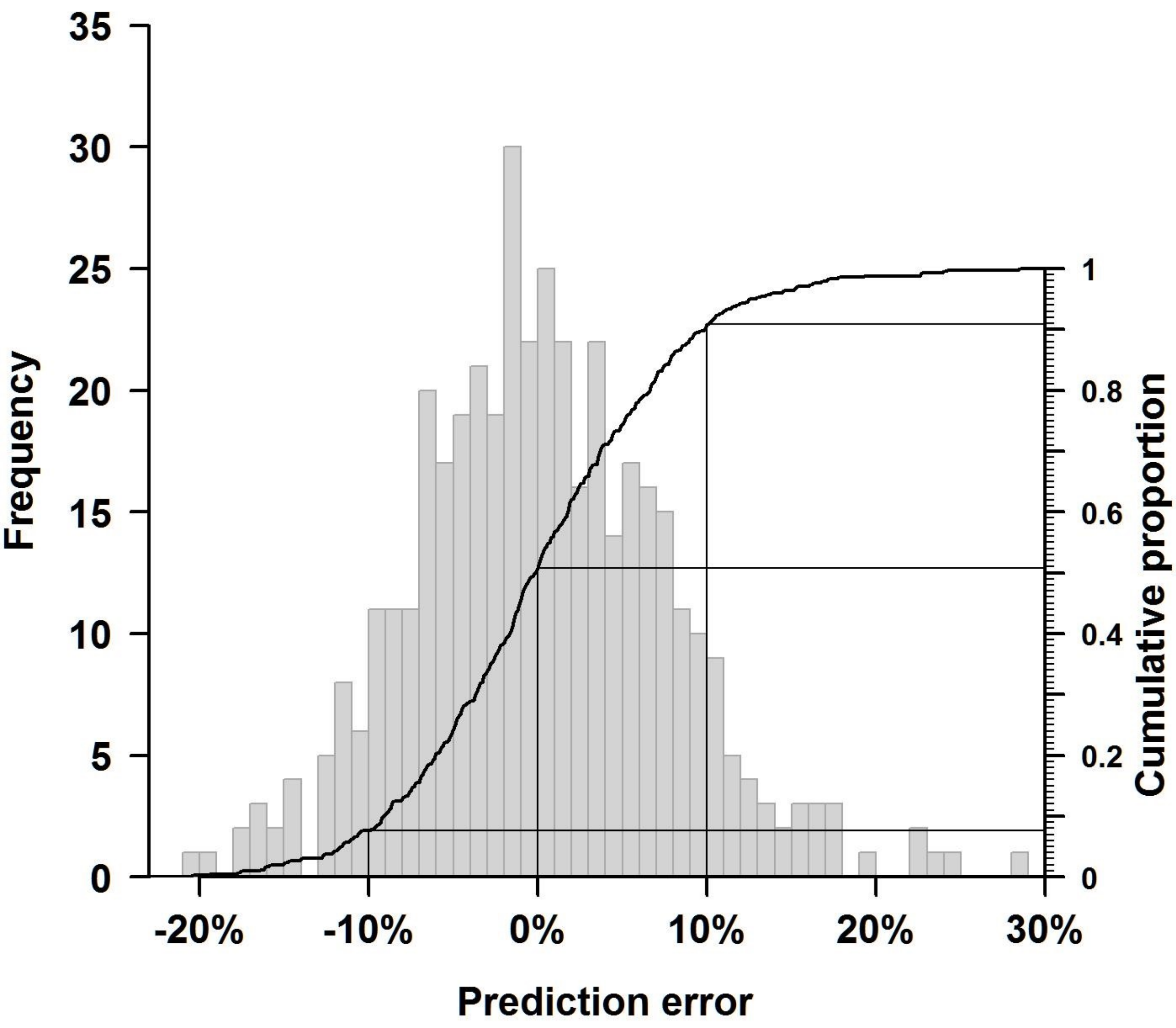
BW = birth weight; EFW = estimated fetal weight; FPR = false positive rate; PPV = positive predictive value; NPV = negative predictive value; AUC = area under receiver operating characteristics curve



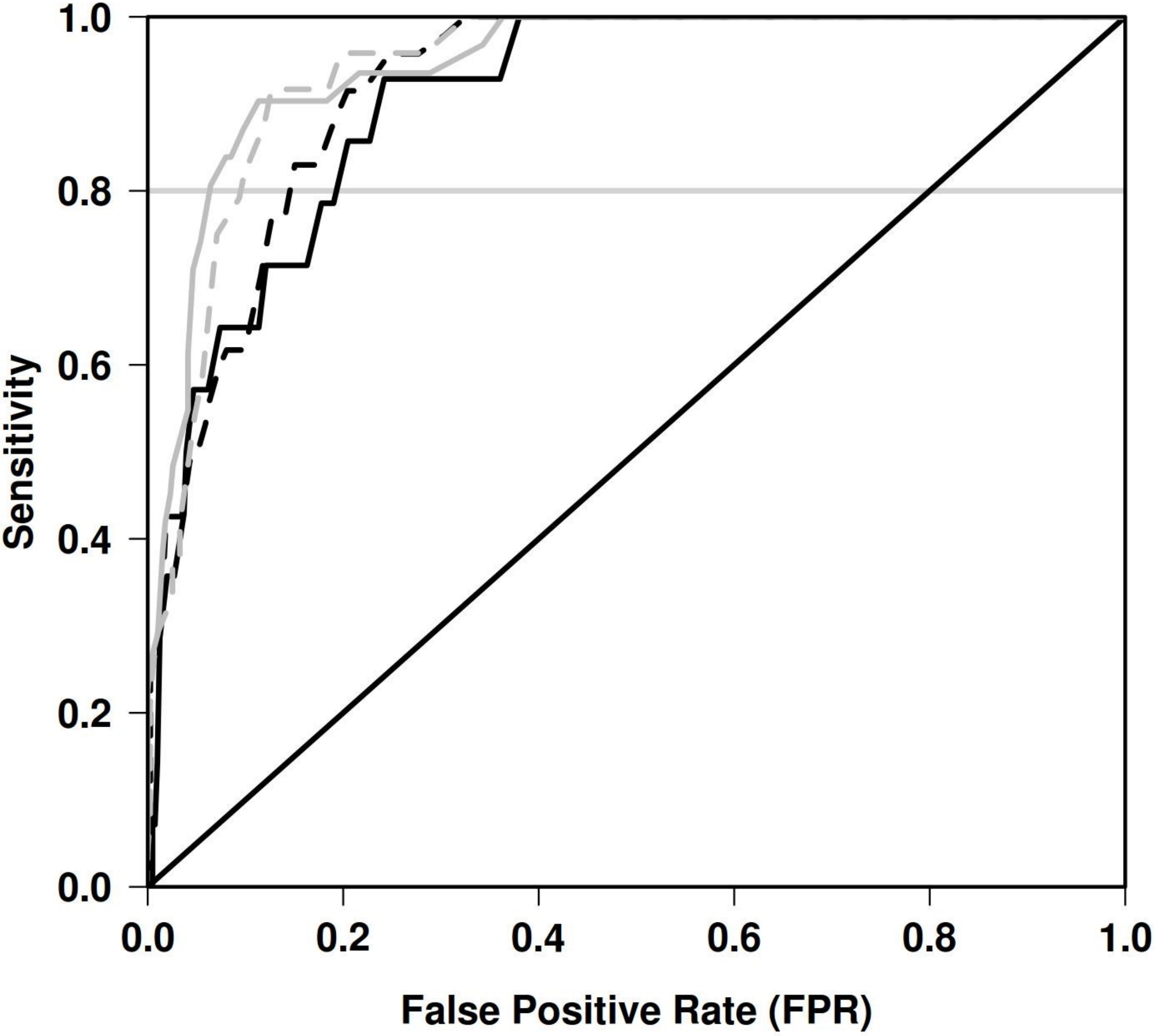
Estimated fetal weight (original and updated)
2500
3000
3500
4000
4500
5000
288
290
292
294
296
Day of pregnancy (ultrasound and birth)



Actual birthweight (grams)
3000
3500
4000
4500
5000
3000
3500
4000
4500
5000
Estimated fetal weight before birth (grams)



35
30
25
20
15
10
5
0
Frequency
1
0.8
0.6
0.4
0.2
0
Cumulative proportion
-20%
-10%
0%
10%
20%
30%
Prediction error



1.0
0.8
0.6
0.4
0.2
0.0
Sensitivity
0.0
0.2
0.4
0.6
0.8
1.0
False Positive Rate (FPR)