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Biparietal diameter for first-trimester pregnancy dating: multicenter cohort study

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KEYWORDS: biparietal diameter; crown–rump length; first trimester; gestational age; pregnancy dating

ABSTRACT

Objective *To evaluate the accuracy of fetal biparietal diameter (BPD) measurement in comparison with crown–rump length (CRL) measurement for pregnancy dating at 11–13 weeks' gestation.*

Methods *This was a retrospective multicenter cohort study performed in five maternity units in Spain, the UK, Belgium and Bulgaria between January 2011 and December 2019. We included all women who attended a routine ultrasound examination at 11 + 0 to 13 + 6 weeks who had a singleton pregnancy with a viable non-malformed fetus/neonate and ultrasound-derived measurements for both CRL and BPD, along with a comprehensive record of pregnancy outcomes. We developed a formula for pregnancy dating based on BPD using data from pregnancies conceived via* in-vitro *fertilization (IVF) by applying a simple linear regression. We validated this formula both internally and externally and compared it with the most commonly used formulae (Robinson's CRL-based and Kustermann's BPD-based formulae) through utilization of the Euclidean distance, relative absolute error and mean squared error. We also examined the rate of induction of labor for post-term pregnancy based on dating using each of the formulae.*

Results *A total of 49 492 women were included in the study, comprising 47 223 (95.4%) who conceived spontaneously and 2269 (4.6%) who conceived via IVF. In the internal validation performed using data from IVF pregnancies, our newly developed formula showed no significant difference when compared with the true gestational age calculated using conception date, with a mean difference of 0.0006 (95% CI, −0.09 to 0.09) days. In contrast, the mean difference of Kustermann's BPD-based formula was −0.31 (95% CI, −0.46 to −0.17) days and the mean difference of Robinson's CRL-based formula was −1.78 (95% CI, −1.88 to −1.68) days. In the external validation using data from spontaneously conceived pregnancies, with dating using Robinson's formula as the reference for 'true' gestational age, both our formula and Kustermann's formula resulted in underestimation of gestational age, with significant mean differences of −1.25 (95% CI, −1.28 to −1.22) days and −0.96 (95% CI, −0.98 to −0.93) days, respectively. The largest differences compared with Robinson's formula-based dating results were observed between 11 + 0 and 12 + 0 weeks. Dating the pregnancy using Robinson's formula led to 8.1% of pregnancies identified as requiring induction after 41 + 3 weeks, compared with 6.8% (P < 0.001) and 7.0% (P < 0.001) when applying our formula and Kustermann's formula, respectively.*

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Conclusion *Pregnancy dating based on ultrasound measurement of fetal BPD between 11 + 0 and 13 + 6 weeks' gestation is a reliable alternative to dating based on fetal CRL.* © *2025 The Author(s). Ultrasound in Obstetrics & Gynecology published by John Wiley & Sons Ltd on behalf of International Society of Ultrasound in Obstetrics and Gynecology.*

INTRODUCTION

Pregnancy dating is essential to mitigate potential complications associated with either preterm or post-term birth[1]. Pregnancy lasts on average 280 days from the first day of the mother's last menstrual period (LMP)[2]. While Naegele's rule[3] is a widely utilized method owing to its simplicity, it tends to be inaccurate, even in women with regular menstrual periods. In comparison with ultrasound measurement of the fetal biparietal diameter (BPD) taken during the second trimester, the LMP method typically underestimates the expected date of delivery (EDD) by approximately 2–3 days[4]. Theoretically, the most accurate method for calculating the EDD involves determining the exact day of conception – an approach applicable exclusively to pregnancies conceived via *in-vitro* fertilization (IVF)[5].

In the case of natural conception, ultrasound assessment has been shown to be the most effective means for dating the pregnancy and estimating the EDD[6,7]. Crown–rump length (CRL) measurement in the first trimester is now recognized universally as the 'gold standard' for pregnancy dating[8,9], providing greater accuracy compared with other biometric parameters such as head circumference or abdominal circumference[10], with a margin of error ranging from 3 to 8 days according to the most commonly used chart, the Robinson chart[11–13]. In the case of IVF pregnancy, the Robinson method tends to overestimate gestational age by 3 days when compared with the true date of conception[14]. When considering other sonographic methods for pregnancy dating in the first trimester, such as measurement of head circumference, abdominal circumference or femur length, BPD appears to be the best alternative to CRL[8,10,11,15,16]. Obtaining a precise CRL measurement requires an extended learning curve and can be particularly challenging in pregnancies at around 13–14 weeks' gestation[17]. In contrast, BPD measurement is reproducible and does not typically need extensive training[10,18,19].

The aim of this study was to evaluate the accuracy of BPD in comparison with CRL for pregnancy dating at 11–13 weeks' gestation.

METHODS

This was a retrospective multicenter cohort study performed at two maternity units in Spain (Hospital Clínico Universitario 'Virgen de la Arrixaca', Murcia and Hospital Universitario de Torrejón, Madrid), one in the UK (King's College Hospital, London), one in Belgium (Brugmann University Hospital, Brussels) and one in Bulgaria (Dr Shterev Hospital, Sofia) between January 2011 and December 2019. Approval for the study and a waiver of consent were obtained from the relevant research ethics committee of each participating center.

We included all women who attended for a routine ultrasound examination at 11 + 0 to 13 + 6 weeks' gestation, who had a singleton pregnancy with a live non-malformed fetus/neonate and ultrasound-derived measurements for both CRL and BPD, along with a comprehensive record of pregnancy outcome. Cases of spontaneous or elective termination or intrauterine death were excluded from the study. Ultrasound measurements and maternal characteristics (weight, height, ethnicity (White, Black, East Asian, South Asian or mixed), method of conception (natural or assisted conception with ovulation drugs or IVF), smoking status during pregnancy, parity, medical history and pregnancy outcome) were obtained from the hospital's electronic clinical database (ViewPoint® Software, GE Healthcare, Munich, Germany; or Astraia® Software, Astraia GmbH, Munich, Germany).

To calculate gestational age, CRL was measured in the midline sagittal section of the whole fetus, oriented horizontally in a neutral position. The maximum distance from the top of the head to the rump of the fetus was measured as a straight line, obtained by placing ultrasound calipers at the outer edges (Figure 1). According to standard recommendations[8,9], three measurements were taken, and the average was considered the final CRL measurement. BPD was measured in the largest symmetrical axial view of the fetal head, demonstrating the skull, midline echo and choroid plexuses, by placing the calipers outer-to-outer, perpendicular to the midline

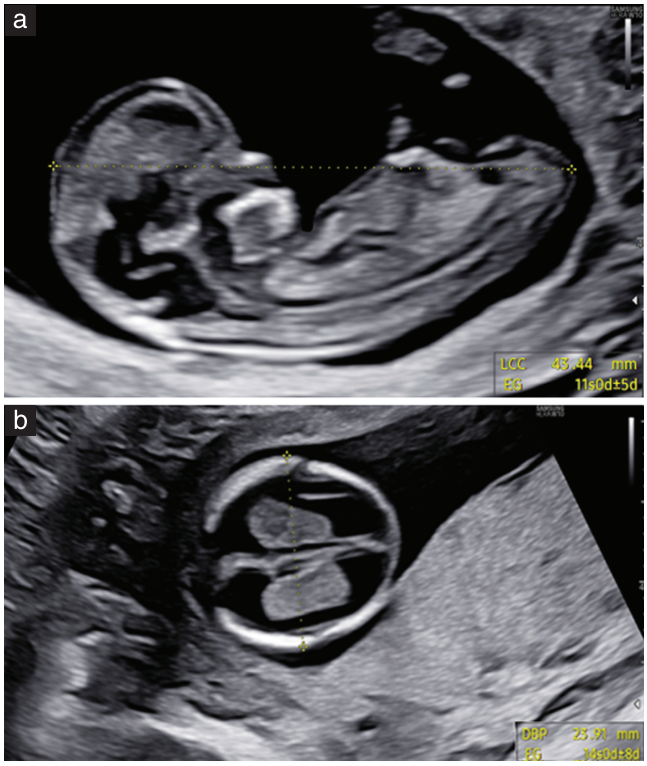

Figure 1 Crown–rump length (a) and biparietal diameter (b) measurements, illustrating the simplicity of obtaining the latter.

falx (Figure 1)[8]. As recommended by the Fetal Medicine Foundation, this view was chosen for BPD measurement owing to its simplicity in early gestation compared with the transthalamic view[9]. Pregnancy dating using BPD was calculated using the formula derived from this study and that published by Kustermann *et al.*[20]. Only CRL, or conception date for IVF pregnancies, was used for pregnancy dating in clinical practice and the BPD measurement was undertaken for other purposes, according to local protocols. Conception date was calculated as the transfer day minus the age of the embryo (i.e. 3 or 5 days). Ultrasound examinations were performed by sonographers or obstetricians certified for nuchal translucency measurement by the Fetal Medicine Foundation.

To validate the formulae across diverse populations, we organized the data by center and analyzed each dataset in the order they were received. The generated dataset was divided into three subgroups. Group 1 ($n = 2269$) included all IVF pregnancies in the maternity units in London and Murcia. This dataset was used to develop the BPD formula for pregnancy dating and was used for internal validation. Group 2 ($n = 47\,223$) included all spontaneous pregnancies in the maternity units in London and Murcia (2013–2017), Brussels (2011–2018), Sofia (2017–2018) and Madrid (2017–2019), and was used for external validation of the model in spontaneously conceived pregnancies. Group 3 ($n = 5256$) was a subset of Group 2, comprising spontaneous pregnancies undergoing induction of labor beyond 41 + 3 weeks ($n = 275$ (5.2%)) and those undergoing spontaneous labor between 34 + 0 and 42 + 6 weeks ($n = 4981$ (94.8%)) in Brussels, Sofia and Madrid (2011–2019), and was used to assess the induction rate due to post-term pregnancy. The cut-off for induction of labor was chosen based on local protocols, which consistently recommended induction of labor by 41 + 3 weeks at the latest for post-term pregnancy, in all participating centers.

Statistical analysis

Continuous data are given as median (interquartile range) and categorical data as *n* (%). To plan the analysis, we visually analyzed the distribution of the two variables. When plotting BPD as the dependent variable and gestational age in days as the independent variable, a completely linear relationship became apparent. Therefore, we chose to fit a simple linear regression model to develop an equation to estimate gestational age based on BPD. All hypotheses of the model were graphically corroborated. When developing the formula and during internal validation (i.e. for Group 1), gestational age calculated using the date of conception was regarded as the gold standard. For external validation (i.e. for Group 2) and assessment of induction rate (i.e. for Group 3), gestational age calculated using Robinson's CRL-based formula was regarded as the gold standard.

To compare gestational age estimation between formulae, the Euclidean distance, relative absolute error (RAE), mean squared error (MSE), mean comparison using the paired *t*-test and range comparison using the Wilcoxon signed-rank test were calculated. For RAE, MSE and Euclidean distance, a smaller value indicates better prediction (i.e. it is closer to the gold standard). In the case of the Wilcoxon signed-rank test and the paired *t*-test, better prediction is indicated when the estimate and 95% CI are closer to 0. The RAE, MSE, *t*-test and Wilcoxon signed-rank test for our formula were estimated by 10-fold cross-validation using data from Group 1. Each parameter was calculated in each fold and their results were averaged. 95% CIs were obtained with 1000 bootstrap replicates. Since Euclidean distance depends on the sample size, it was calculated for the whole sample.

We conducted a final comparison between formulae based on the number of pregnancies identified as requiring induction of labor owing to post-term pregnancy, defined as cases in which spontaneous labor did not commence within 41 + 3 weeks/290 days, according to each formula. We used the McNemar test to assess the difference in induction rate when using each pregnancy-dating method.

All analyses were carried out using R software version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria)[21]. 'Car' package was used to clean the data[22], 'caret' package was used to create the folds for the cross validation[23], 'lubridate' package was used to manage the dates[24] and 'ggplot2' package was used for plots and figures[25]. $P < 0.05$ was considered to indicate statistical significance.

RESULTS

A total of 49 492 women were included in the study, comprising 47 223 (95.4%) women in Group 2 who conceived spontaneously and 2269 (4.6%) women in Group 1 who conceived via IVF. Group 3 comprised 5256 women from Group 2 who conceived spontaneously, of whom 275 (5.2%) underwent induction of labor after 41 + 3 weeks and 4981 (94.8%) underwent spontaneous labor between 34 + 0 and 42 + 6 weeks. Maternal and pregnancy baseline characteristics are presented in Table 1.

Development of BPD formula

Group 1 data were used initially to derive a formula for predicting gestational age (in days) using BPD measurement, using a cross-validated linear regression model: gestational age (days) = (BPD (mm) + 16.33798) / 0.4299. Subsequently, we compared the gestational age prediction derived from our formula with that derived from the formula of Kustermann[20] (using BPD) and that of Robinson[12] (using CRL) (Table 2). While Robinson's formula had the smallest global error, our newly developed formula showed the smallest mean and range differences compared with the true gestational age (based on date of conception), closely followed by Kustermann's formula. Our formula did not demonstrate a statistically significant difference from the gold standard, differing by a mean of 0.0006 (95% CI, −0.09 to 0.09) days. Kustermann's and Robinson's formulae showed a mean difference of −0.31

Table 1 Maternal and pregnancy baseline characteristics of study cohort

Characteristic	*Group 1 (n = 2269)*	*Group 2 (n = 47 223)*	*Group 3 (n = 5256)*
Maternal age (years)	37.0 (34.0–40.0)	32.0 (28.0–36.0)	29.4 (25.7–33.4)
Maternal ethnic origin			
Black	49 (2.2)	6995 (14.8)	679 (12.9)
East Asian	50 (2.2)	1111 (2.4)	15 (0.3)
Mixed	31 (1.4)	1166 (2.5)	9 (0.2)
South Asian	116 (5.1)	2086 (4.4)	76 (1.4)
White	2023 (89.2)	35 865 (75.9)	4477 (85.2)
Maternal body mass index (kg/m^2)	23.3 (21.3–26.2)	23.9 (21.4–27.5)	24.6 (21.8–28.1)
Nulliparous	1617 (71.3)	20 914 (44.3)	1754 (33.4)
Smoker	63 (2.8)	2442 (5.2)	407 (7.7)
Conception			
In-vitro fertilization	2269 (100)	0 (0)	0 (0)
Spontaneous	0 (0)	47 223 (100)	5256 (100)
Chronic hypertension	13 (0.6)	400 (0.8)	53 (1.0)
Diabetes mellitus	9 (0.4)	309 (0.7)	32 (0.6)
Gestational age at ultrasound (days)*	87.0 (85.0–90.0)	89.0 (86.3–91.6)	89.1 (86.0–92.1)

Data are given as median (interquartile range) or *n* (%). *Estimated according to routine clinical practice i.e. conception date for pregnancies conceived by *in-vitro* fertilization and crown–rump length for spontaneously conceived pregnancies.

Table 2 Internal validation of our formula, Kustermann's formula[20] and Robinson's formula[12] for pregnancy dating, using Group 1 data (conception via *in-vitro* fertilization)

Formula	*RAE*	*MSE*	*Euclidean distance*	*Mean difference from gold standard (days)*	*Range difference from gold standard (days)**
Our formula	1.02 (0.99–1.04)	14.94 (14.19–15.92)	184 (179–190)	0.0006 (−0.09 to 0.09)	−0.02 (−0.12 to 0.06)
Kustermann[20]	0.94 (0.91–0.98)	12.83 (12.07–13.67)	170 (165–176)	−0.31 (−0.46 to −0.17)	−0.34 (−0.48 to −0.20)
Robinson[12]	0.80 (0.77–0.83)	9.30 (8.68–9.99)	145 (140–151)	−1.78 (−1.88 to −1.68)	−1.73 (−1.83 to −1.64)

Data are given as estimate (95% CI), unless stated otherwise. *Data are given as pseudomedian (95% CI). In all cases, gold standard is true gestational age calculated using conception date. MSE, mean squared error; RAE, relative absolute error.

(95% CI, −0.46 to −0.17) days and −1.78 (95% CI, −1.88 to −1.68) days, respectively, with respect to the true gestational age calculated using the date of conception. While the MSE and RAE highlight occasional large errors in the BPD formulae, the mean difference and range difference show that most BPD predictions are closer to the observed values, indicating less systematic bias (Table 2).

Figure 2 provides a visual representation of the predicted gestational age calculated using each formula compared with the true gestational age based on date of conception. Both of the formulae that use BPD provided similar estimates, especially after 13 weeks, and showed excellent concordance with the true gestational age. In contrast, the CRL formula overestimated gestational age, particularly at 11–12 weeks.

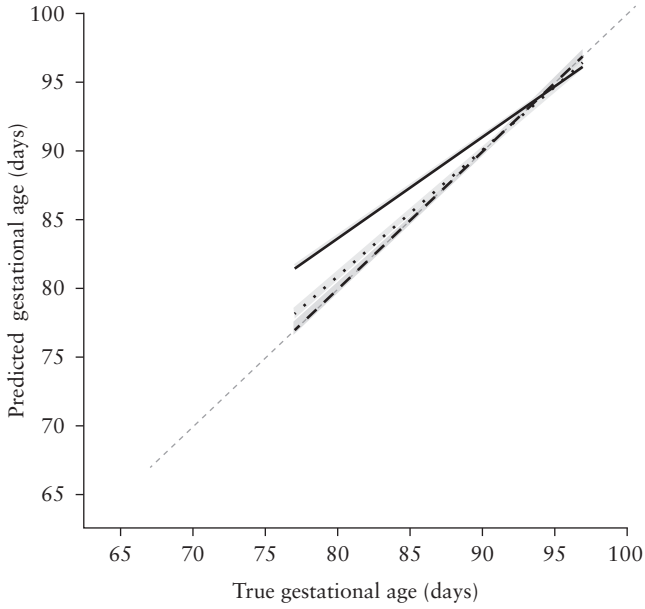

Figure 2 Gestational age calculated using our formula (– –), Kustermann's formula[20] (· · · ·) and Robinson's formula[12] (——) for pregnancy dating, in comparison with true gestational age calculated based on conception date, using Group 1 data. Gray dashed line represents maximum possible agreement between true and predicted gestational age. Gray shaded areas are 95% CI.

External validation in spontaneously conceived pregnancies

Group 2 data were used for the external validation of our formula and comparison with Robinson's and Kustermann's formulae, applied to spontaneously conceived pregnancies. In this analysis, we regarded gestational age calculated using Robinson's CRL-based dating as the 'true' gestational age (Table 3, Figure 3), as the conception date in spontaneous pregnancies is unknown. Both

Table 3 External validation of our formula and Kustermann's formula[20] for pregnancy dating, using Group 2 data (spontaneous conception)

Formula	*RAE*	*MSE*	*Euclidean distance*	*Mean difference from gold standard (days)*	*Range difference from gold standard (days)**
Our formula	0.87 (0.86–0.88)	11.27 (11.11–11.43)	730 (724–734)	−1.25 (−1.28 to −1.22)	−1.31 (−1.34 to −1.29)
Kustermann[20]	0.76 (0.75–0.77)	8.72 (8.60–8.85)	641 (637–647)	−0.96 (−0.98 to −0.93)	−1.01 (−1.04 to −0.99)

Data are given as estimate (95% CI), unless stated otherwise. *Data are given as pseudomedian (95% CI). In all cases, gold standard is 'true' gestational age estimated from crown–rump length using Robinson's formula[12]. MSE, mean squared error; RAE, relative absolute error.

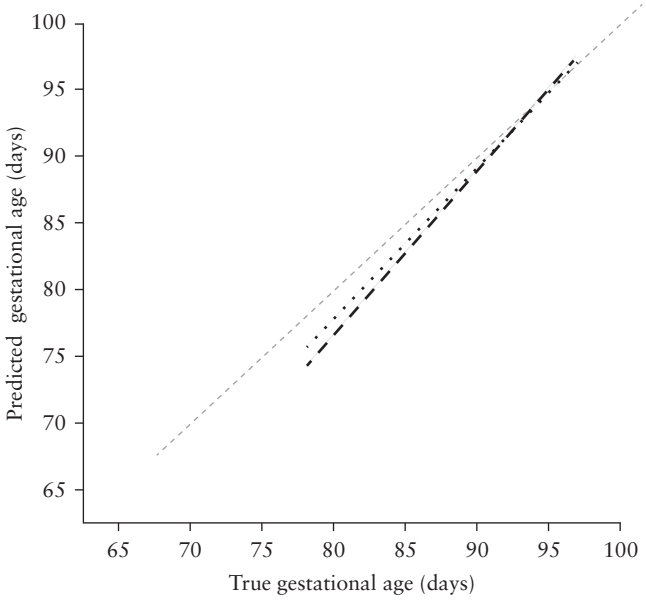

Figure 3 Gestational age calculated using our formula (– –) and Kustermann's formula[20] (· · · ·) for pregnancy dating, in comparison with 'true' gestational age calculated based on Robinson's crown–rump-length-based dating formula[12], using Group 2 data. Gray dashed line represents maximum possible agreement between 'true' and predicted gestational age. Gray shaded areas are 95% CI.

BPD-based formulae showed a statistically significant underestimation of gestational age when compared with gestational age calculated using Robinson's formula, with a mean difference of −1.25 (95% CI, −1.28 to −1.22) days and −0.96 (95% CI, −0.98 to −0.93) days using our formula and Kustermann's formula, respectively. The largest differences compared with Robinson's formula were observed between 11 + 0 and 12 + 0 weeks, but the differences diminished thereafter. Bland–Altman plots for dating using our formula and Kustermann's formula are given in Figures S1 and S2, respectively.

Rate of induction of labor for post-term pregnancy

Group 3 data were used to estimate the induction rate after 41 + 3 weeks, derived using each of the three abovementioned formulae. When pregnancy dating was performed using Robinson's CRL-based formula, there were 426 (8.1%) cases identified as requiring subsequent induction of labor. Dating using our BPD-based formula resulted in 355 (6.8%) cases identified as requiring induction, and dating using Kustermann's BPD-based formula resulted in 366 (7.0%) cases identified as requiring induction. The number of cases identified as requiring induction of labor using our formula and Kustermann's formula was significantly different from that identified using Robinson's formula, with the former requiring fewer inductions ($P < 0.001$ for both). There was no difference between the number of cases identified as requiring induction of labor using our formula and that using Kustermann's formula ($P = 0.1$).

DISCUSSION

Main findings

There were four main findings of this study. First, pregnancy dating based on ultrasound measurement of fetal BPD during the first-trimester scan, especially when performed after 12 weeks' gestation, provided a reliable alternative to dating based on ultrasound measurement of fetal CRL. Second, BPD-based dating presented a closer concordance with the true gestational age (calculated from conception date in IVF pregnancies) when compared with CRL-based dating. Third, EDD calculated using BPD-based or CRL-based dating methods differed by less than a day on average. Fourth, pregnancy dating using first-trimester BPD measurements did not result in a higher rate of post-term induction of labor in comparison with dating using CRL measurements.

Comparison with results of previous studies

Many studies have examined potential methods for pregnancy dating in the first trimester, with a focus not only on accuracy but also on measurement reproducibility. However, these studies were small and lacked external validation. Two studies[10,26] found that CRL and BPD were equally accurate in predicting the EDD. Chalouhi *et al.*[10] developed dating formulae for CRL and BPD using data from 331 IVF pregnancies, which were subsequently validated in 3667 pregnancies, most of which were spontaneous. Similar to our findings, they concluded that both CRL and BPD measurements were highly reproducible and could predict the EDD with great accuracy. Wu *et al.*[26] investigated BPD as an alternative to CRL for the determination of gestational age in 167 IVF pregnancies. They found that the BPD-based dating formula had a significantly smaller mean difference from conception date-based estimates compared with the CRL formula (0.013 *vs* 0.746; $P < 0.01$), with a lower SD (2.414 *vs* 3.008; $P < 0.05$). Consequently, they

suggested that BPD might offer similar accuracy to CRL in pregnancy dating[26].

Two other studies[14,27] reported that BPD measurement is preferable to CRL for pregnancy dating. Knight *et al*.[14] analyzed 178 pregnancies conceived via IVF at 11 + 2 to 14 + 1 weeks' gestation and compared dating using Robinson's CRL-based formula with dating based on conception date. Similar to our findings, they observed a mean overestimation of 3.0 (95% CI, 2.70–3.36) days when using Robinson's formula[14]. Sladkevicius *et al*.[27] evaluated the accuracy of 21 CRL-based dating formulae and three BPD-based dating formulae using data from 167 singleton IVF pregnancies. They reported that the three BPD formulae outperformed all 21 CRL formulae, as they presented smaller random errors. All but two CRL-based dating formulae displayed systematic overestimation or underestimation of gestational age, with SDs ranging from 2.25 to 4.86 days[27].

Strengths and limitations

The main strength of this study lies in the large sample size, which allowed us to divide the dataset into different subgroups and perform different validations across different populations. The importance of external validation is that, before a predictive model can be considered for use in clinical practice, its performance must be evaluated in populations distinct from those used in its development[28]. This extends beyond evaluation at a different point in time; external validation in a different geographical area serves as a robust measure of the model's generalizability and transportability. Furthermore, the large number of included IVF pregnancies enabled us to develop a precise formula and validate the two formulae that are most commonly used for pregnancy dating.

The main limitations of this study are related to its retrospective design. We were unable to evaluate other factors that may have been of interest after obtaining the results, such as operator experience or reproducibility. Another limitation to consider is that, as BPD was not the standard method for pregnancy dating in any of the participating centers, the measurements may not have been performed as meticulously as were CRL measurements, which is the clinical standard for dating. This could have led potentially to an underestimation of the accuracy of the BPD methods. A common limitation of validation studies is that they do not allow for distinguishing differences due to population-specific characteristics or different measurement techniques for the validation of the model itself. Therefore, each population may require specific adjustments once its characteristics are known[29].

Implications for clinical practice

Measuring fetal BPD is a relatively straightforward procedure, as reference points or landmarks for BPD are readily identifiable and do not necessitate advanced ultrasound expertise or high-resolution equipment. Owing to its simplicity and accessibility, employing BPD measurement for pregnancy dating in areas with limited ultrasound training opportunities could enhance its widespread use, potentially reducing complications arising from inaccurate dating. Furthermore, although it is not typically required in routine clinical protocols, BPD measurement may be useful in clinical situations such as persistent inadequate fetal positioning, which is relatively common by the end of the 13th week of pregnancy. In this case, using BPD for pregnancy dating with either our formula or Kustermann's formula can shorten the examination time and thus improve clinical efficiency.

Conclusions

This study has demonstrated that pregnancy dating based on ultrasound measurement of fetal BPD between 11 + 0 and 13 + 6 weeks' gestation is a reliable alternative to dating based on fetal CRL. Dating using BPD differs by less than a day from dating using CRL, with no increase in the rate of induction of labor due to prolonged gestation.

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SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Figure S1 Bland–Altman analysis of our newly developed biparietal-diameter-based dating formula *vs* Robinson's crown–rump-length-based dating formula, using Group 2 data. Red line represents mean difference (days) between the two methods and blue lines represent 95% CI.

Figure S2 Bland–Altman analysis of Kustermann's biparietal-diameter-based dating formula *vs* Robinson's crown–rump-length-based dating formula, using Group 2 data. Red line represents mean difference (days) between the two methods and blue lines represent 95% CI.