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The value of ultrasound in the prediction of successful induction of labor

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KEYWORDS: body mass index; cervical length; gestational age; induction of labor; maternal age; occipital position; parity; posterior cervical angle; ultrasound

ABSTRACT

Objectives *To examine the value of pre-induction sonographic assessment of cervical length, posterior cervical angle and occipital position in the prediction of the induction-to-delivery interval within 24 h, the likelihood of vaginal delivery within 24 h, the likelihood of Cesarean section and to compare sonographic assessment with the Bishop score.*

Methods *In 604 singleton pregnancies, induction of labor was carried out at 35–42 weeks of gestation. Immediately before induction, transvaginal sonography was performed for measurement of cervical length and posterior cervical angle and a transabdominal scan was carried out to determine the position of the fetal occiput. The value of occipital position, posterior cervical angle, cervical length, parity, gestational age, maternal age, and body mass index (BMI) on the induction-to-delivery interval within 24 h, the likelihood of vaginal delivery within 24 h and the likelihood of Cesarean section were investigated by Cox proportional hazard model or logistic regression analysis.*

Results *Vaginal delivery occurred in 484 (80.1%) women and this was within 24 h of induction in 388 (64.2%). Cesarean section was performed in 120 (19.9%). Occiput-anterior (OA) and transverse (OT) positions were analyzed as one group as the odds ratios (OR) and the HR were similar and different from occiput-posterior (OP), which was analyzed as another group. Prediction of the induction-to-delivery interval was provided by the occipital position, pre-induction cervical length, parity and posterior cervical angle. Prediction of the likelihood of vaginal delivery within 24 h was provided by the occipital position, cervical length, posterior cervical angle and BMI. Prediction of the likelihood of Cesarean section was provided by the occipital position, cervical length, parity, maternal age and BMI. In the prediction of vaginal delivery within 24 h, for a specificity of 75%, the sensitivity for ultrasound findings was 89% and for the Bishop score it was 65%. The respective sensitivities for Cesarean section were 78% and 53%.*

Conclusion *In women undergoing induction of labor, significant independent prediction of the induction-to-delivery interval within 24 h, the likelihood of vaginal delivery within 24 h and the likelihood of Cesarean section are provided by pre-induction cervical length, occipital position, posterior cervical angle and maternal characteristics. Sonographic parameters were superior to the Bishop score in the prediction of the outcome of induction. Copyright © 2004 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

One in five pregnant women undergoes induction of labor but 20% of these have an emergency Cesarean section[1–3]. Extensive research has demonstrated that measuring pre-induction cervical length sonographically, in addition to parity, gestational age, maternal age and body mass index (BMI), provides a useful prediction of the induction-to-delivery interval, the likelihood of vaginal delivery within 24 h and the likelihood of Cesarean section[4–8]. For example, the likelihood of a Cesarean section increases by about 10% with each increase of 1 mm in cervical length above 20 mm, and the odds are about 75% lower in parae compared to nulliparae with the same cervical length[7]. In this study we investigated two additional sonographic parameters, fetal occipital position and posterior cervical angle, that may help improve prediction of the outcome

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of induction. Furthermore, we compare sonographic assessment with the Bishop score.

Clinical studies have established that the incidence of Cesarean section is substantially higher in occiput-posterior (OP) rather than occiput-anterior (OA) deliveries[9–10]. Fetal occipital position can now be determined easily by transabdominal ultrasound during labor[11–13]. Posterior cervical angle, which is the angle between the posterior uterine wall and the cervical canal, has been proposed as a more accurate reflection of the position of the cervix, which is a component of the Bishop score[14]. A study involving induction of labor in 50 singleton pregnancies reported that the median pre-induction posterior cervical angle in those delivered by Cesarean section was more acute than in those who delivered vaginally (60° vs. 90°)[14].

The aim of this study was to examine the value of pre-induction sonographic assessment of cervical length, posterior cervical angle and occipital position in the prediction of the induction-to-delivery interval within 24 h, the likelihood of vaginal delivery within 24 h, the likelihood of Cesarean section and to compare sonographic assessment with the Bishop score.

METHODS

This was a prospective study of 604 singleton pregnancies that attended for induction of labor at St. Mary's Hospital, Portsmouth, UK. The entry criteria were live fetuses in cephalic presentation, undergoing induction of labor at 35 to 42 + 6 weeks of gestation for a variety of indications. Some of the data from these pregnancies were included in previous reports[6–8]. All women gave their written informed consent to participate in the study, which was approved by the Research and Ethics Committee of the hospital.

Immediately before induction, transvaginal sonography was performed for measurement of cervical length and posterior cervical angle and a transabdominal scan was carried out to determine the position of the fetal occiput. Subsequently, an experienced obstetrician (consultant or registrar) or midwife who was not aware of the sonographic findings, assessed the Bishop score[15]. The methodology for measurement of cervical length[16,17], determination of the fetal occiput[11–13] and induction of labor[18] are as previously described. For determination of the fetal head position the ultrasound transducer was first placed transversely in the suprapubic region of the maternal abdomen. The landmarks depicting fetal position were the fetal orbits for OP position, the midline cerebral echo for occiput-transverse (OT) positions and cerebellum or occiput for OA position. The findings were recorded in a data sheet depicting a circle, like a clock, with 24 divisions, and the position was described as anterior (OA) if the occiput was between 09.30 and 02.30 h, transverse (OT) if between 02.30 and 03.30 h, or 08.30 and 09.30 h, and posterior (OP) if between 03.30 and 08.30 h (Figures 1 and 2). The posterior cervical angle was measured with a protractor applied to a hard copy picture taken in a sagittal plane at the level of the internal os and approximated to the nearest 10° (Figure 3). In the case of a funneled or an excessively curved cervix, the angle was assessed at the junction of the line measuring the cervical length and posterior uterine wall.

Standard accepted definitions of active labor and failure to progress were used[18].

Statistical analysis

The women were divided into subgroups according to parity (nulliparae and parae), BMI (< 30 and ≥ 30), occipital positions (OA + OT and OP) and posterior cervical angle ($< 120°$ and $\geq 120°$). Sonographic cervical length, gestational age at induction, maternal age and the Bishop score were assessed as continuous variables. Times that exceeded 24 h or which resulted from Cesarean sections were treated as censored. The effect of occipital position, posterior cervical angle, sonographic cervical length, parity, gestational age, maternal age and BMI on the induction-to-delivery interval within 24 h, the likelihood of vaginal delivery within 24 h and the likelihood of Cesarean section were investigated by Cox proportional hazard model and logistic regression analysis, respectively. Stratified statistical analysis showed that there was a significant interaction between occipital position and cervical length, posterior cervical angle and BMI. Hence, the outcome measures of time to delivery within 24 h, likelihood of vaginal delivery within 24 h and likelihood of Cesarean section were analyzed separately according to the position of the occiput. Continuous variables were analyzed as such because after testing linearity on a logarithmic scale the assumption of proportionality was found to be appropriate. Categorical variables were dichotomized appropriately after testing proportionality. BMI was analyzed in two categories, because on univariate analysis the odds ratios (OR) and the hazard ratios (HR) for BMI divided into groups of five in predicting the outcome measures, were similar at BMI ≥ 30 and different from BMI < 30. The OR and the HR for all BMI groups of < 30 and the groups of ≥ 30 were

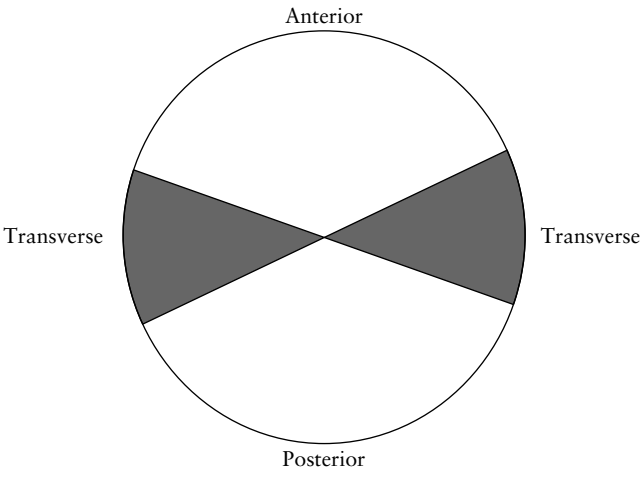

Figure 1 Description of occipital positions.

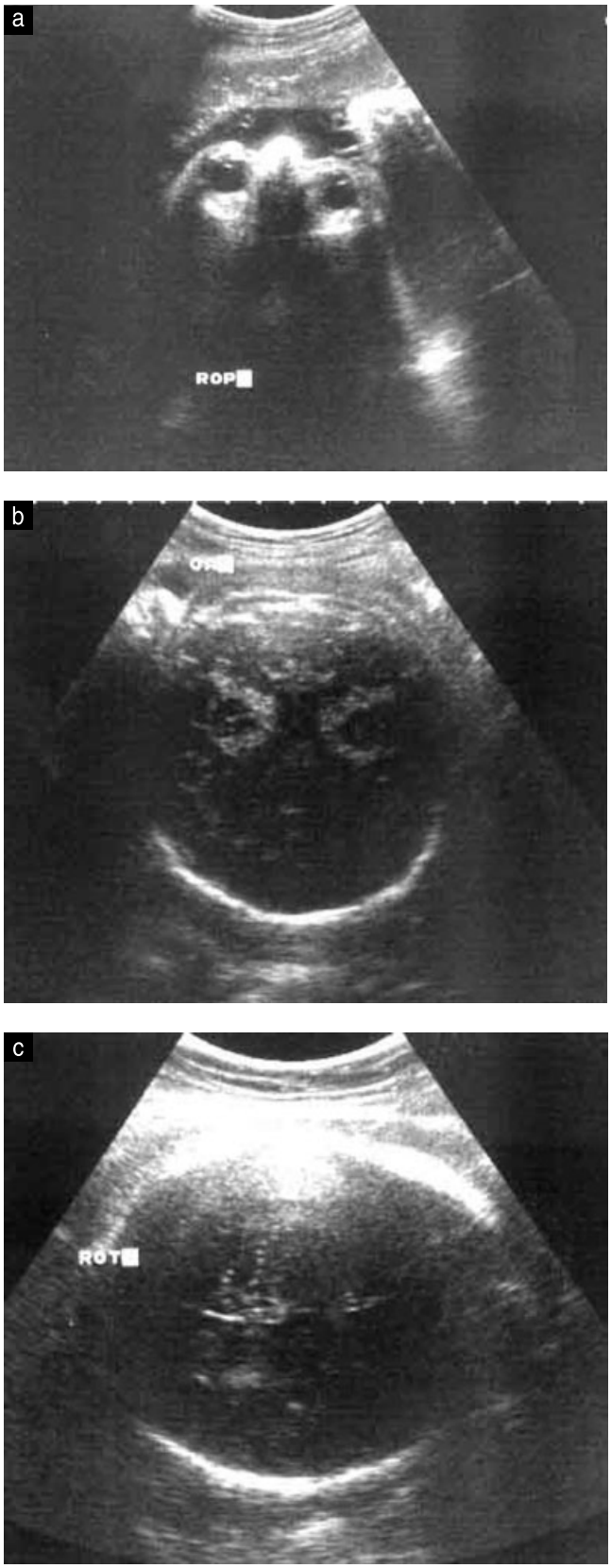

Figure 2 Occipital positions on ultrasound. (a) Occiput posterior. (b) Occiput anterior. (c) Occiput transverse.

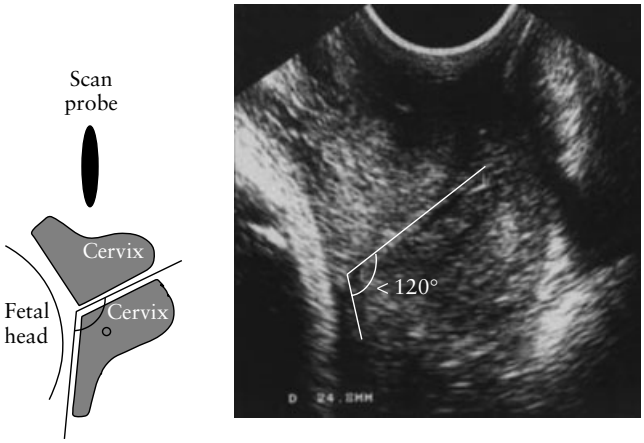

Figure 3 Reference points for measuring posterior cervical angle and ultrasound picture demonstrating this measurement.

similar to each other. Maternal age was analyzed as a continuous variable, as the OR and HR were similar above and below 35 and 40 years for the respective outcome measures, and did not significantly contribute to predicting them as categorical variables. Further, stratified statistical analysis showed that there was a significant interaction between occipital position and cervical length, posterior cervical angle and BMI. Hence, the outcome measures of time to delivery within 24 h, likelihood of vaginal delivery within 24 h and likelihood of Cesarean section were analyzed separately according to the position of the occiput. OA and OT positions were analyzed as one group and OP as another group.

Logistic regression analysis was also used to predict the likelihood of vaginal delivery within 24 h and the likelihood of Cesarean section by the Bishop score and maternal characteristics. The final logistic regression models, using ultrasound findings with maternal characteristics and Bishop score with maternal characteristics, were used to calculate the probability scores for vaginal delivery within 24 h and Cesarean section for each woman. For different probability cut-offs the sensitivity, specificity, positive (PPV) and negative (NPV) predictive values were calculated. In the comparison of the receiver–operating characteristics (ROC) curves, the area under the curve is usually the best descriminator[19]. Two-sided *P*-values are reported throughout.

RESULTS

We assessed 610 patients undergoing induction of labor but in six cases ultrasound examination demonstrated that the fetus was in breech presentation and they were excluded from the study for not meeting the entry criteria. Their management, including external cephalic version, was subsequently changed according to the hospital protocol for breech presentation. Sonographic measurement of cervical length, assessment of occipital position and measurement of posterior cervical angle were successfully carried out in all 604 pregnancies. The indications for induction are shown in Table 1 and demographic characteristics of the study population are shown in Table 2. The commonest indication for

Table 1 Indications for induction of labor in the study population

Indication	n *(%)*
Prolonged pregnancy	221 (36.6)
Hypertension in pregnancy	85 (14.1)
Small for dates	73 (12.1)
Prelabor rupture of membranes	57 (9.4)
Maternal request	44 (7.3)
Large for dates	37 (6.1)
Maternal disease	32 (5.3)
Antepartum hemorrhage	21 (3.5)
Past obstetric history	18 (3.0)
Diabetes in pregnancy	16 (2.6)

Table 2 Demographic characteristics of the study population

Characteristic	n *(%)*
Parity	
Nulliparae	263 (43.5%)
Parae	341 (56.5%)
Ethnicity	
Caucasian	592 (98%)
Afro-Caribbean	3 (0.5%)
Asian	8 (1.3%)
Oriental	1 (0.2)
Maternal age (years, median (range))	30 (16–47)
Gestational age (weeks, median (range))	40.1 (35–42.7)
Body mass index	26 (15–57)

induction was prolonged pregnancy beyond 290 days of gestation. The pre-induction position of the fetal occiput was OA in 168 (27.8%) of cases, OT in 218 (36.1%) and OP in 218 (36.1%). The posterior cervical angle was $< 120°$ in 252 (41.7%) cases and $\geq 120°$ in 352 (58.3%).

Successful vaginal delivery occurred in 484 of the 604 (80.1%) women and this was within 24 h of induction in 388 (64.2%). Cesarean section was performed in 120 (19.9%), including 42 for fetal distress and 78 for failure to progress. In 58 cases Cesarean section was performed within 24 h of induction, including 31 for fetal distress and 27 for failure to progress. In cases where both failure to progress and fetal distress occurred, we considered the primary indication for which the Cesarean section was done.

The relationship between pre-induction cervical length and the induction-to-delivery interval and the likelihood of Cesarean section in nulliparae and parae are shown in Figures 4 and 5, respectively. Cox proportional hazard model for OA and OT positions indicated that significant independent prediction of the induction-to-delivery interval within 24 h was provided by cervical length and parity (Table 3a), whereas for OP positions significant independent prediction was provided by posterior cervical angle, cervical length, and parity (Table 4a).

The estimated probability of giving birth at any particular time for a typical mother with OA or OT occipital position was calculated from the baseline survival function (Table 3b). The baseline survival function assumes

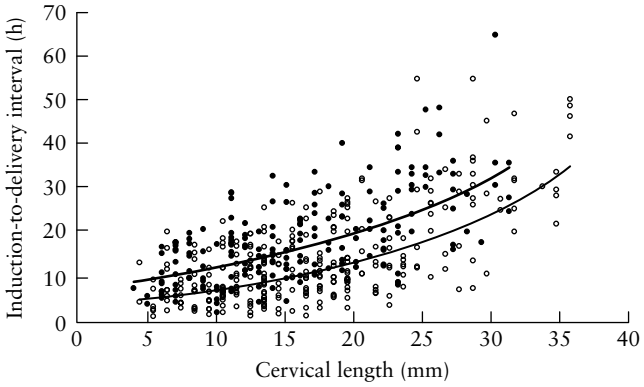

Figure 4 Association between pre-induction cervical length measured sonographically and the induction-to-delivery interval (h) in nulliparae (bold line and •) and parae (thin line and ◦). Equation for induction-to-delivery interval in nulliparae as linearized estimates (Exp1ntial): induction-to-delivery interval = 8.20 exp(4.30E−02 (cervix (mm))). Correlation coefficient $r = 0.581$ ($r^2 = 0.338$) and in parae (Exp1ntial): induction-to-delivery interval = 4.321 exp(0.056 (cervix (mm))). Correlation coefficient $r = 0.597$, ($r^2 = 0.356$).

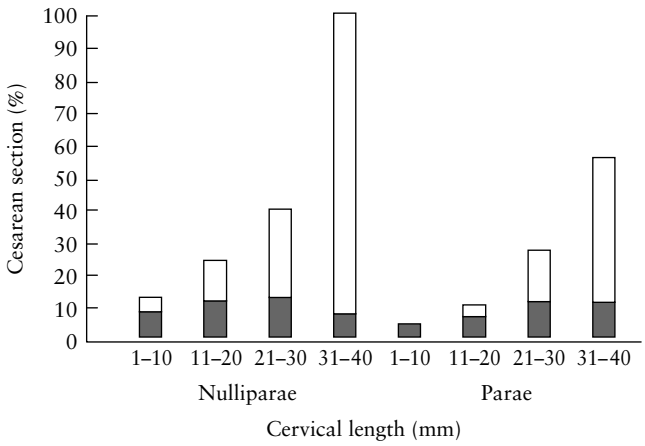

Figure 5 Association between pre-induction cervical length and the likelihood of Cesarean section for fetal distress (■) and failure to progress (□) in nulliparae and parae.

mean values for the six predictors as follows: cervix of 16.5 mm, posterior cervical angle of 0.6, parity of 0.6, BMI of 0.3, gestational age of 39.9 weeks and maternal age of 29.3 years. To compute the probability of being in labor for a particular woman we calculated the survival time (S(t)), from the exponential of c. Hence, $S(t)^{\exp(c)}$, where c = (−0.1215 (cervix − 16.5538) + 0.1735 (posterior cervical angle − 0.6089) + 0.5645 (parity − 0.5722) + 0.2438 (BMI − 0.3018) + 0.0484 (gestational age − 39.8766) + 0.0138 (maternal age − 29.3150)), where parity = 0 for nulliparae and 1 for parae, posterior cervical angle = 0 if $< 120°$ and 1 if $\geq 120°$, and BMI = 0 if < 30 and 1 if ≥ 30. For example, in a 30-year-old parous woman with a cervical length of 15 mm, BMI of < 30, posterior cervical angle of $\geq 120°$ and at 38 weeks' gestation: c = (−0.1215 (15 − 16.5538) + 0.1735 (1 − 0.6089) + 0.5645 (1 − 0.5722) + 0.2438 (0 − 0.3018) +

Table 3a Results of Cox proportional hazard model of induction-to-delivery interval within 24 h for occiput anterior or transverse position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*HR*	*95% CI*	P	*HR*	*95% CI*	P
Posterior cervical angle			< 0.0001			0.199
< 120° (0)	1.00			1.00		
≥ 120° (1)	1.78	1.38–2.30		1.19	0.91–1.55	
Cervical length	0.89	0.87–0.91	< 0.0001	0.88	0.87–0.90	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	1.70	1.33–2.19		1.76	1.36–2.27	
Body mass index			0.588			0.079
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.93	0.71–1.21		1.28	0.97–1.67	
Gestational age	1.06	0.98–1.14	0.108	1.05	0.97–1.13	0.199
Maternal age	1.00	0.98–1.02	0.885	1.01	0.99–1.04	0.194

HR, hazard ratio.

Table 3b Probability of being in labor or having delivered at different times from survival curves plotted for women having characteristics that are means of the different variables and with occiput in anterior or transverse position

Time (h)	P (Labor) = S(t)	P (Delivery) = *1* − S(t)
3	0.9896	0.0104
6	0.9264	0.0736
9	0.8123	0.1877
12	0.6876	0.3124
15	0.5468	0.4532
18	0.4225	0.5775
21	0.2906	0.7094
24	0.2146	0.7854

S(t), survival function for time.

$0.0484\ (38 - 39.8766) + 0.0138\ (30 - 29.3150))$, $c = -0.0275 \Rightarrow \exp(-0.0275) = 0.9729$. Thus, the probability of being in labor = $S(t)^{0.9729}$. Therefore, the probability of this woman being in labor at 6 h is $0.9264^{0.9729} = 0.9283$ or 92.8%, and the probability that she will give birth within 6 h of induction is $1 - 0.9283 = 0.0716$ or 7.2%. The formula for predicting time to delivery in the OP position is $c = (-0.1734\ (x - 16.6774) + 0.4486\ (x - 0.5300) + 1.4758\ (x - 0.5438) - 0.3677\ (x - 0.2903) - 0.0173\ (x - 29.2673) + 0.0361\ (x - 39.9184))$, where x is the variable particular to the woman for induction of labor (Table 4b). Using $S(t)^c$, time to delivery can be predicted as in the example above.

Logistic regression analysis indicated that significant independent prediction of the likelihood of vaginal delivery within 24 h for OA and OT positions was provided by pre-induction cervical length and parity (Table 5) and for OP positions by cervical length, parity, posterior cervical angle and BMI (Table 6). Logistic regression analysis also showed that for OA, OT and OP positions the likelihood of Cesarean section was significantly predicted by pre-induction cervical length, parity, maternal age and BMI (Tables 7 and 8). The characteristics of the different formulae proposed to predict the likelihood of vaginal delivery within 24 h

Table 4a Results of Cox proportional hazard model of induction-to-delivery interval within 24 h for occiput posterior position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*HR*	*95% CI*	P	*HR*	*95% CI*	P
Posterior cervical angle			< 0.0001			0.0382
< 120° (0)	1.00			1.00		
≥ 120° (1)	2.76	1.87–4.08		1.57	1.02–2.39	
Cervical length	0.85	0.83–0.88	< 0.0001	0.84	0.81–0.87	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.26	1.55–3.28		4.37	2.81–6.82	
Body mass index			0.005			0.127
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.52	0.33–0.83		0.69	0.43–1.11	
Gestational age	1.08	0.96–1.20	0.194	1.04	0.91–1.18	0.588
Maternal age	1.01	0.98–1.03	0.672	0.98	0.95–1.01	0.272

HR, hazard ratio.

Table 4b Probability of being in labor or having delivered at different times from survival curves plotted for women having characteristics that are means of the different variables and with occiput in posterior position

Time (h)	P(Labor) = S(t)	P(Delivery) = *1* − S(t)
3	0.9822	0.0178
6	0.9473	0.0527
9	0.871	0.129
12	0.8223	0.1777
15	0.7404	0.2596
18	0.6417	0.3583
21	0.5247	0.4753
24	0.4392	0.5608

S(t), survival function for time.

and the likelihood of Cesarean section for the different occipital positions are shown in Table 9. This table shows that an OP position on its own is associated with a significantly reduced likelihood of vaginal delivery within 24 h and a significantly increased likelihood of Cesarean section.

In the case of the Bishop score, logistic regression analysis showed that the likelihood of vaginal delivery within 24 h was significantly predicted by Bishop score, parity and BMI (Table 10) and the likelihood of Cesarean section was significantly predicted by Bishop score, parity, BMI and maternal age (Table 11).

The sensitivity, specificity, PPV and NPV of the different cut-offs of probability for delivery within 24 h and Cesarean section using the formulas of ultrasound findings with maternal characteristics are shown in Tables 12 and 13. For example, about 10% of the women had an estimated probability for Cesarean section of ≥ 0.4 and 59% of these women had a section. Furthermore, this group contained 48% of all women who had a Cesarean section. Similarly, we can define a group with a high likelihood of vaginal delivery within 24 h of induction. For example, 59% of the women had an estimated probability for vaginal delivery within 24 h of ≥ 0.5, and 85% of these women had such a delivery. Furthermore, this group contained 92% of all women who had a vaginal delivery within 24 h of induction.

ROC curves, comparing the predictions provided by the ultrasound findings with maternal characteristics, the Bishop score with maternal characteristics and the Bishop score alone, are shown in Figures 6 and 7. In the prediction of vaginal delivery within 24 h, for a specificity of 75% the respective sensitivities for ultrasound findings with maternal characteristics, the Bishop score with maternal characteristics and the Bishop score alone were 89%, 68% and 65%, and the respective percentage areas

Table 5a Logistic regression analysis for likelihood of vaginal delivery within 24 h for occiput anterior or transverse position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Posterior cervical angle			0.001			0.881
< 120° (0)	1.00			1.00		
≥ 120° (1)	2.14	1.38–3.32		1.04	0.59–1.85	
Cervical length	0.82	0.78–0.85	< 0.0001	0.81	0.77–0.85	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.404	1.32–3.17		3.01	1.66–5.46	
Body mass index			0.393			0.525
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.82	0.51–1.30		1.22	0.66–2.25	
Gestational age	1.14	1.01–1.29	0.040	1.10	0.94–1.28	0.245
Maternal age	0.98	0.94–1.02	0.238	0.98	0.93–1.03	0.446

AOR, adjusted odds ratio; OR, odds ratio.

Table 5b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of vaginal delivery within 24 h for occiput anterior or transverse position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Cervical length	0.82	0.78–0.85	< 0.0001	0.81	0.78–0.85	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.04	1.32–3.17		2.79	1.60–4.84	

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of vaginal delivery within 24 h for occiput anterior or transverse position: $Y = \log_e$ (odds) = (4.054 − 0.210 (cervical length (in mm)) + 1.024 (1 for para, 0 for nullipara)), odds = e^y, risk = odds/1 + odds.

Table 6a Logistic regression analysis for likelihood of vaginal delivery within 24 h for occiput posterior position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Posterior cervical angle			< 0.0001			0.001
< 120° (0)	1.00			1.00		
≥ 120° (1)	4.83	2.72–8.60		4.40	1.86–10.43	
Cervical length	0.78	0.73–0.83	< 0.0001	0.76	0.71–0.83	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.68	1.55–4.65		8.99	3.30–24.5	
Body mass index			< 0.0001			0.003
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.33	0.18–0.61		0.21	0.07–0.58	
Gestational age	1.13	0.96–1.33	0.139	1.02	0.79–1.32	0.891
Maternal age	0.993	0.95–1.04	0.731	0.95	0.89–1.02	0.180

AOR, adjusted odds ratio; OR, odds ratio.

Table 6b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of vaginal delivery within 24 h for occiput posterior position

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Posterior cervical angle			< 0.0001			0.001
< 120° (0)	1.00			1.00		
≥ 120° (1)	4.83	2.72–8.60		4.05	1.74–9.41	
Cervical length	0.78	0.73–0.83	< 0.0001	0.77	0.71–0.83	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.68	1.55–4.65		6.94	2.81–17.17	
Body mass index			< 0.0001			0.001
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.33	0.18–0.61		0.20	0.07–0.53	

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of vaginal delivery within 24 h for occiput posterior position: $Y = \log_e$ (odds) = (3.309 − 0.266 (cervical length (in mm)) + 1.938 (1 for para, 0 for nullipara) + 1.399 (1 for posterior cervical angle ≥ 120°, 0 for posterior angle < 120°) − 1.619 (1 for BMI ≥ 30, 0 for BMI < 30)), odds = e^y, risk = odds/1 + odds.

Table 7a Logistic regression analysis for likelihood of Cesarean section for occiput anterior and transverse positions

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Posterior cervical angle			0.034			0.925
< 120° (0)	1.00			1.00		
≥ 120° (1)	0.55	0.32–0.96		1.03	0.54–1.96	
Cervical length	1.12	1.08–1.17	< 0.0001	1.12	1.08–1.17	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.22–0.67		0.26	0.14–0.50	
Body mass index			0.143			0.580
< 30 (0)	1.00			1.00		
≥ 30 (1)	1.53	0.87–2.71		1.20	0.62–2.32	
Gestational age	0.86	0.74–0.998	0.047	0.90	0.75–1.05	0.173
Maternal age	1.05	0.997–1.1	0.065	1.06	1.00–1.11	0.049

AOR, adjusted odds ratio; OR, odds ratio.

Table 7b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of Cesarean section for occiput anterior and transverse positions

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Cervical length	1.12	1.08–1.17	< 0.0001	1.13	1.08–1.17	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.22–0.67		0.27	0.14–0.51	
Maternal age	1.02	1.00–1.05	0.104	1.06	1.00–1.12	0.035

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of Cesarean section for occiput anterior or transverse position: $Y = \log_e$ (odds) = (−4.969 + 0.118 (cervical length (in mm)) − 1.316 (1 for para, 0 for nullipara) + 0.058 (maternal age (in years))), odds = e^y, risk = odds/1 + odds.

Table 8a Logistic regression analysis for likelihood of Cesarean section for occiput posterior positions

	Univariate analysis			*Multivariate analysis*		
Variable	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Posterior cervical angle			0.002			0.248
< 120° (0)	1.00			1.00		
≥ 120° (1)	0.38	0.21–0.71		0.64	0.30–1.36	
Cervical length	1.15	1.1–1.20	< 0.0001	1.13	1.08–1.19	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.21–0.71		0.25	0.12–0.55	
Body mass index			0.001			0.008
< 30 (0)	1.00			1.00		
≥ 30 (1)	2.88	1.53–5.43		2.88	1.33–6.26	
Gestational age	0.94	0.78–1.12	0.466	0.98	0.79–1.21	0.879
Maternal age	1.01	0.96–1.06	0.734	1.02	0.96–1.08	0.549

AOR, adjusted odds ratio; OR, odds ratio.

Table 8b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of Cesarean section for occiput posterior positions

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Cervical length	1.15	1.1–1.20	< 0.0001	1.14	1.09–1.20	< 0.0001
Parity			< 0.0001			0.001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.21–0.71		0.27	0.13–0.56	
Body mass index			0.001			0.007
< 30 (0)	1.00			1.00		
≥ 30 (1)	2.88	1.53–5.43		2.881	1.34–6.20	

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of Cesarean section for occiput posterior position: $Y = \log_e$ (odds) = (−3.174 + 0.134 (cervical length (in mm)) − 1.322 (1 for para, 0 for nullipara) + 1.058 (1 for BMI ≥ 30, 0 for BMI < 30)), odds = e^y, risk = odds/1 + odds.

under the curve were 89%, 78% and 75% (Figure 6). In the prediction of likelihood of Cesarean section, for a specificity of 75% the respective sensitivities for ultrasound findings with maternal characteristics, the Bishop score with maternal characteristics and the Bishop score alone were 78%, 59% and 53%, and the respective percentage areas under the curve were 81%, 75% and 68% (Figure 7).

DISCUSSION

In women undergoing induction of labor, pre-induction sonographic assessment of cervical length, posterior cervical angle and occipital position is superior to the Bishop score in the prediction of outcome of labor. For the same specificity of 75%, the sensitivity of sonographic assessment in the prediction of Cesarean section and

Table 9 Characteristics of the proposed formulae from Tables 5b to 8b

Test (95% CI, median (range))	*Vaginal delivery in 24 h*		*Cesarean section*	
	OA/OT	*OP*	*OA/OT*	*OP*
Prevalence	69.2 (64.3–73.7)	55.5 (48.6–62.2)	15.8 (12.3–19.8)	27.1 (21.3–33.5)
Sensitivity	91.8 (87.8–94.8)	90.1(83.3–94.8)	19.7 (10.6–31.8)	47.5 (34.3–60.9)
Specificity	60.5 (51.1–69.3)	78.4 (68.8–86.1)	98.2 (96–99.3)	89.3 (83.4–93.7)
PPV	83.9 (79.2–87.9)	83.9 (76.4–89.7)	66.7 (41–86.7)	62.2 (46.5–76.2)
NPV	76.6 (66.7–84.7)	86.4 (77.4–92.8)	13.3 (10–17.2)	82.1 (75.5–87.5)
LR	2.3 (1.88–3.0)	4.2 (2.9–6.19)	10.7 (4.27–26.37)	4.4 (2.6–7.5)

LR, likelihood ratio; NPV, negative predictive value; OA, occiput-anterior position; OP, occiput-posterior position; OT, occiput-transverse position; PPV, positive predictive value.

Table 10a Logistic regression analysis for likelihood of vaginal delivery within 24 h

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Bishop score	1.63	1.47–1.81	< 0.0001	1.60	1.44–1.78	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	2.40	1.32–3.17		2.39	1.61–3.57	
Body mass index			0.393			0.002
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.82	0.51–1.30		0.521	0.34–0.77	
Gestational age	1.14	1.01–1.29	0.040	1.10	0.99–1.22	0.135
Maternal age	0.98	0.94–1.02	0.238	0.97	0.94–1.00	0.291

AOR, adjusted odds ratio; OR, odds ratio.

Table 10b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of vaginal delivery within 24 h

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Bishop score	1.63	1.47–1.81	< 0.0001	1.62	1.45–1.80	< 0.0001
Parity			< 0.0001			0.0002
Nulliparae (0)	1.00			1.00		
Parae (1)	2.404	1.32–3.17		2.05	1.41–2.99	
Body mass index			0.393			0.0008
< 30 (0)	1.00			1.00		
≥ 30 (1)	0.82	0.51–1.30		0.50	0.34–0.75	

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of Cesarean section for occiput posterior position:
$Y = \log_e$ (odds) = (−1.6057 + 0.4810 (Bishop score) + 0.7020 (1 for para, 0 for nullipara) − 0.6845 (1 for BMI ≥ 30, 0 for BMI < 30)),
odds = e^y, risk = odds/1 + odds.

likelihood of vaginal delivery within 24 h of induction was higher than that of the Bishop score by about 20%.

The finding that about 20% of singleton pregnancies undergoing induction deliver by Cesarean section is compatible with the results of previous reports[1–3]. Similarly, the effects of parity, maternal age and BMI as well as pre-induction cervical length are now well established[4–8,20–24]. This study has demonstrated the additional significant contribution of occipital position and posterior cervical angle in predicting the outcome of induction of labor. Although occipital position is related to cervical length, being shorter in OA and OT than in OP positions, the occipital position enhances the effect of cervical length in the prediction of outcome. The OP position also relates to maternal pelvic architecture and is indicative of where the fetal occiput finds the greatest room. This may influence the entire course of labor and it is also a significant contributor to the outcome of induction of labor. The posterior cervical angle provides an accurate measure of the position of the cervix and when the angle is < 120° there is prolongation of labor.

Table 11a Logistic regression analysis for likelihood of Cesarean section

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Bishop score	0.72	0.65–0.80	< 0.0001	0.74	0.66–0.83	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.21–0.71		0.35	0.22–0.54	
Body mass index			0.001			0.0003
< 30	1.00			1.00		
≥ 30	2.88	1.53–5.43		2.26	1.45–3.52	
Gestational age	0.94	0.78–1.12	0.466	0.92	0.82–1.04	0.199
Maternal age	1.01	0.96–1.06	0.734	1.05	1.01–1.09	0.124

AOR, adjusted odds ratio; OR, odds ratio.

Table 11b Logistic regression analysis with a reduced model produced by forward and backward stepwise conditional elimination method for likelihood of Cesarean section

	Univariate analysis			*Multivariate analysis*		
Variable (predictor)	*OR*	*95% CI*	P	*AOR*	*95% CI*	P
Bishop score	0.72	0.65–0.80	< 0.0001	0.74	0.66–0.82	< 0.0001
Parity			< 0.0001			< 0.0001
Nulliparae (0)	1.00			1.00		
Parae (1)	0.38	0.21–0.71		0.36	0.23–0.56	
Body mass index			0.001			0.0005
< 30 (0)	1.00			1.00		
≥ 30 (1)	2.88	1.53–5.43		2.24	1.44–3.48	
Maternal age	1.01	0.96–1.06	0.734	1.05	1.01–1.09	0.010

AOR, adjusted odds ratio; OR, odds ratio. Formula to predict likelihood of Cesarean section for occiput posterior position: $Y = \log_e$ (odds) = (−1.2516 − 0.3064 (Bishop score) − 1.0351 (1 for para, 0 for nullipara) + 0.8063 (1 for BMI ≥ 30, 0 for BMI < 30) + 0.0464 (maternal age in (years))), odds = e^y, risk = odds/1 + odds.

Table 12 Sensitivity, specificity, positive and negative predictive values for different cut-offs of probability for likelihood of vaginal delivery within 24 h predicted from the multiple regression models of ultrasound findings and maternal characteristics (Tables 5b and 6b)

Predicted probability	*Screened positive* n *(%)*	*Sensitivity (%)*	*Specificity (%)*	*Positive predictive value (%)*	*Negative predictive value (%)*
< 0.1	219 (36.3)	0.8	71.8	04.7	28.7
≥ 0.1	385 (63.7)	99.2	28.2	71.3	95.3
≥ 0.2	379 (62.7)	97.7	43.1	75.5	91.2
≥ 0.3	377 (62.4)	97.2	53.7	79.0	91.3
≥ 0.4	367 (60.8)	94.6	63.9	82.5	86.8
≥ 0.5	357 (59.1)	92.0	70.8	85.0	83.2

We have established a series of models that can classify women into high- and low-risk groups for Cesarean section and provide individual patient predictions for outcome of induction of labor. For example, in a 35-year-old nulliparous woman with BMI ≥ 30 and the sonographic findings of cervical length of 30 mm, posterior cervical angle < 120° and fetal OP position the likelihood of Cesarean section is 87%. On the other hand, in a 25-year-old parous woman with BMI < 30 and cervical length of 10 mm, posterior cervical angle > 120° and fetal OA position the likelihood of vaginal delivery within 24 h is 95% and the likelihood of Cesarean section is 2.5%.

In women undergoing induction of labor, prediction of outcome can be provided by determining sonographically the pre-induction cervical length, occipital position and posterior cervical angle, in addition to traditional maternal characteristics. Sonographic parameters are superior to the Bishop score in the prediction of the

Table 13 Sensitivity, specificity, positive and negative predictive values for different cut-offs of probability for likelihood of Cesarean section predicted from the multiple regression models of ultrasound findings and maternal characteristics (Tables 7b and 8b)

Predicted probability	*Screened positive* n *(%)*	*Sensitivity (%)*	*Specificity (%)*	*Positive predictive value (%)*	*Negative predictive value (%)*
< 0.1	503 (83.3%)	15.8	48.8	07.1	70.0
⩾ 0.1	101 (16.7%)	84.2	51.2	30.3	92.9
⩾ 0.2	86 (14.2%)	71.7	76.2	42.8	91.6
⩾ 0.3	68 (11.3%)	56.7	87.4	52.7	89.1
⩾ 0.4	58 (9.6%)	48.3	91.5	58.6	87.7
⩾ 0.5	42 (7.0%)	35.0	95.7	66.6	85.6

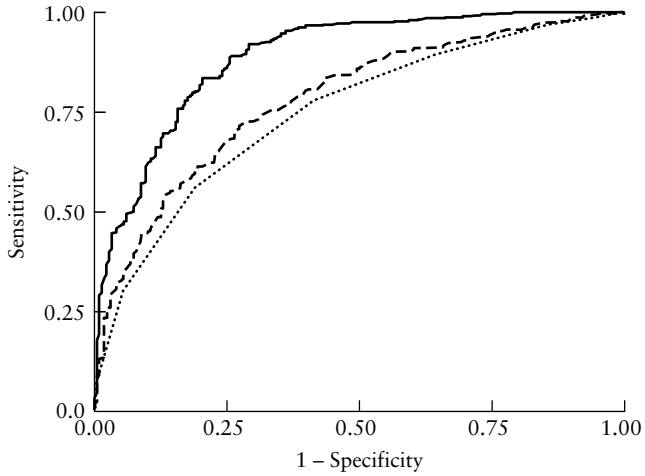

Figure 6 Receiver–operating characteristics (ROC) curves for the three methods of assessment comparing the predictions provided by the ultrasound findings with maternal characteristics (solid line), the Bishop score with maternal characteristics (dashed line) and the Bishop score alone (dotted line) for the likelihood of vaginal delivery within 24 h.

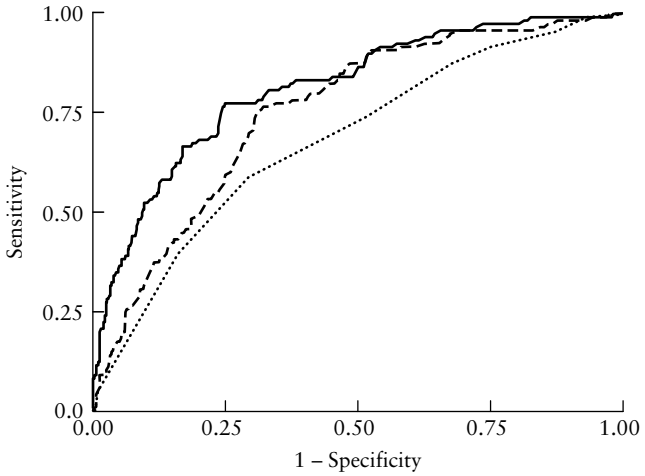

Figure 7 Receiver–operating characteristics (ROC) curves for the three methods of assessment comparing the predictions provided by the ultrasound findings with maternal characteristics (solid line), the Bishop score with maternal characteristics (dashed line) and the Bishop score alone (dotted line), for the likelihood of Cesarean section.

outcome of induction. Using pre-induction sonographic parameters and maternal characteristics to predict the outcome of induction enables the clinician to provide precise information to the mothers, and accordingly, plan further management of the pregnancy.

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