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MATERNAL-FETAL MEDICINE

Predictive model for risk of cesarean section in pregnant women after induction of labor

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Abstract
Purpose To develop a predictive model for risk of cesarean section in pregnant women after induction of labor.
Methods A retrospective cohort study was conducted of 861 induced labors during 2009, 2010, and 2011 at Hospital "La Mancha-Centro" in Alcázar de San Juan, Spain. Multivariate analysis was used with binary logistic regression and areas under the ROC curves to determine predictive ability. Two predictive models were created: model A predicts the outcome at the time the woman is admitted to the hospital (before the decision to of the method of induction); and model B predicts the outcome at the time the woman is definitely admitted to the labor room.
Results The predictive factors in the final model were: maternal height, body mass index, nulliparity, Bishop score, gestational age, macrosomia, gender of fetus, and the gynecologist's overall cesarean section rate. The predictive ability of model A was 0.77 [95 % confidence interval (CI) 0.73–0.80] and model B was 0.79 (95 % CI 0.76–0.83). The predictive ability for pregnant women with previous cesarean section with model A was 0.79 (95 % CI 0.64–0.94) and with model B was 0.80 (95 % CI 0.64–0.96). For a probability of estimated cesarean section $\geq$80 %, the models A and B presented a positive likelihood ratio (+LR) for cesarean section of 22 and 20, respectively. Also, for a likelihood of estimated cesarean section $\leq$10 %, the models A and B presented a +LR for vaginal delivery of 13 and 6, respectively.
Conclusion These predictive models have a good discriminative ability, both overall and for all subgroups studied. This tool can be useful in clinical practice, especially for pregnant women with previous cesarean section and diabetes.

Keywords Induction of labor · Cesarean section · Predictive model

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Introduction

Labor induction (LI) is when labor is started by medical or surgical procedures before the onset of spontaneous labor [1]. It is one of the most common interventions in obstetrics, and in European countries it is practiced in 6.8–33.0 % of all pregnancies [2]. In addition, there is a growing tendency in its employment at increasingly younger gestational ages [3].

This procedure not only has significant medical implications for the mother and fetus, but also directly affects the health-care system (because of the extra workload and use of resources) and the woman's childbirth experience [1].

LI is associated with an increase in complications compared with spontaneous labor [4–8] and results in a larger number of cesarean sections. Specifically, after controlling for other factors, LI is associated with 20 % of all cesarean sections [9]. In addition, LI that ends in cesarean section has worse outcomes when compared to cesarean section without labor [10].

Often, when there is a particular complication during pregnancy, the only options are LI or cesarean section. In such situations, clinicians must decide between these two options. However, this decision is complex, because it involves many factors and there can be great uncertainty about the outcome.

As such, one of the most important challenges facing obstetrics is being able to predict labor outcome, especially in induced labor, to minimize the risks of both induction and cesarean section. In this regard, some authors have developed predictive models aimed at determining the personal and obstetric characteristics associated with an increased risk of cesarean section.

Most of these models compare the predictive ability of cervical length as measured by ultrasound with the Bishop score (BS) right before LI, with varying results [11, 12]. However, labor outcome can also be determined by other clinical and personal aspects, and even by the professionals involved. Nevertheless, few studies have incorporated a combination of the different factors involved in LI in pregnant women, resulting in disparate predictors and outcomes [13–21].

The objective of this study was to develop a model that can be used to predict labor outcome in pregnant women who undergo LI that integrates variables related to anthropometric, obstetric, cervical and fetal characteristics and those of the attending health-care professionals.

Methods

Design

This was an observational, analytical study of retrospective cohorts. It was conducted in the Obstetrics Unit of Hospital "Mancha-Centro" in Alcázar de San Juan (Ciudad Real, Spain) during 2009, 2010, and 2011.

Subjects

The reference population was a set of pregnant women whose labor was induced at Hospital "La Mancha-Centro." Exclusion criteria were unavoidable emergency cesarean section (breech presentation, transverse lie, deflected cephalic presentation, and vaginal delivery ruled out due to previous cesarean section), twin pregnancy, and dead fetus antepartum.

In our center, the medical criteria for LI follow the guidelines of the Spanish Society of Gynecology and Obstetrics (SEGO) [1].

The induction methods were: preinduction cervical ripening if Bishop score ≤6 and use of dinoprostone 10 mg administered vaginally; oxytocin infusion and amniotomy if Bishop score >6.

Calculating the number of subjects required

In constructing a multivariate analysis model, ten events (cesarean section) per variable are required for it to be incorporated. Assuming a maximum of ten variables in the initial model, a single year would be enough, but because of possibly incomplete records and indications for induction, the data collection period was extended to 3 years (2009, 2010, and 2011).

Sources of information

To collect the information, we used hospital records and the regional electronic information system for primary care for the patients being studied.

The following variables were collected:

Primary outcome variables: cesarean delivery (yes/no).

Independent variables:

- Maternal: overall maternal age (years), categorized maternal age (≤20, 21–34, ≥35 years), overall maternal height (cm), categorized maternal height (<150, 150–169, ≥170 cm), overall body mass index (BMI) (kg/m^2), and categorized BMI (<25, 25–29, ≥30).
- Obstetrics: previous cesarean section, parity (nulliparous/multiparous), BS at hospital admission, BS at admission to labor room, use of prostaglandins, time since premature rupture of membranes (PROM), oligohydramnios (amniotic fluid index <5), intrauterine fetal growth restriction (IUFGR), hypertension, diabetes (gestational and pre-gestational, with or without control depending on gestational age), fertility treatment, and pathological fetal heart rate (FHR).
- Fetal: gender of newborn, overall neonatal birth weight (grams), categorized neonatal birth weight (<2500, 2500–2999, 3000–3499, 3500–3999, ≥4000 g), macrosomia (≥4000 g), gestational age (weeks), and categorized gestational age (<37, 37–41, >41 weeks).
- Related to the gynecologist indicating the cesarean section: age of the gynecologist (<35, 35–40, 40–45, >45 years), gender, and personal rate of emergency cesarean sections performed by the gynecologist in charge in this period.

Statistical analysis

First, a univariate analysis of potential predictive factors was performed using the Chi-squared test and/or Student's

Table 1 Potential predictors related to type of delivery

Predictor	Labor outcome		
	Vaginal ($n = 594$)	Cesarean section ($n = 247$)	P value
Age (years)	31.1 ± 5.3	30.8 ± 5.4	0.348
Maternal age			0.935
≤20 years	18 (69.2)	8 (30.8)	
21–35 years	434 (70.3)	183 (29.7)	
>35 years	41 (71.6)	56 (28.4)	
Gestational age (weeks)	39.1 ± 1.6	39.3 ± 1.8	0.197
Gestational age			0.014
37	41 (60.3)	27 (39.7)	
37–41	435 (73.5)	157 (26.5)	
≥41	117 (65.0)	63 (35.0)	
Parity			<0.001
Nulliparity	337 (61.4)	212 (38.6)	
Multiparity	254 (88.2)	34 (11.8)	
Previous cesarean section			0.005
No	570 (71.6)	226 (28.4)	
Yes	21 (51.2)	20 (48.8)	
Diabetes			0.248
No	411 (69.3)	182 (30.7)	
Yes	153 (73.6)	55 (26.4)	
Hypertension			0.556
No	521 (70.7)	216 (29.3)	
Yes	43 (67.2)	21 (32.8)	
PROM (minutes)	250.6 ± 543.7	351.0 ± 1293.6	0.246
PROM			0.394
≤24 h	476 (70.9)	195 (29.1)	
>24 h	86 (67.2)	42 (32.8)	
Oligohydramnios			0.138
No	528 (69.9)	227 (30.1)	
Yes	66 (77.6)	19 (22.4)	
IUFGR			0.676
No	569 (70.8)	235 (29.2)	
Yes	25 (67.6)	12 (32.4)	
Pathological FHR			0.588
No	583 (70.8)	241 (29.2)	
Yes	11 (64.7)	6 (35.3)	
Antepartum meconium			0.616
No	584 (70.5)	244 (29.5)	
Yes	10 (76.9)	3 (23.1)	
BMI (kg/m^2)	24.9 ± 4.52	26.2 ± 5.2	0.002
BMI (3 categories)			0.013
<25	308 (75.1)	102 (24.9)	
25–29.9	149 (67.4)	72 (32.6)	
≥30	70 (62.5)	42 (37.5)	
Height (cm)	163.1 ± 6.2	162.0 ± 5.85	0.028
Height (3 categories)			0.008
<150	6 (50.0)	6 (50.0)	
150–169	442 (69.5)	194 (30.5)	
≥170	81 (82.7)	17 (17.3)	
Previous labor induction			0.129
No	496 (69.6)	217 (30.4)	
Yes	57 (78.1)	16 (21.9)	

Table 1 continued

Predictor	Labor outcome		
	Vaginal ($n = 594$)	Cesarean section ($n = 247$)	P value
Fertility treatment			0.052
No	585 (71.1)	238 (28.9)	
Yes	9 (50.0)	9 (50.0)	
Use of dinoprostone			0.065
No	237 (74.1)	83 (25.9)	
Yes	327 (68.0)	154 (32.0)	
Bishop score at hospital admission	2.8 ± 1.95	1.9 ± 1.74	<0.001
Bishop score at admission to labor room	5.3 ± 2.23	3.9 ± 2.28	<0.001
Neonatal birth weight (g)	3110.9 ± 461.1	3162 ± 540.7	0.191
Neonatal birth weight			0.007
<2500	52 (64.2)	29 (35.8)	
2500–2999	191 (77.0)	57 (23.0)	
3000–3499	225 (70.1)	96 (29.9)	
3500–3999	111 (69.4)	49 (30.6)	
≥4000	15 (48.4)	16 (51.6)	
Gender of newborn			0.018
Male	277 (66.6)	139 (33.4)	
Female	285 (74.2)	99 (25.8)	
Gender of doctor			0.539
Male	198 (71.0)	81 (29.0)	
Female	396 (70.5)	166 (29.5)	
Age of doctor			0.002
<35 years	98 (63.6)	56 (36.4)	
35–40 years	117 (73.1)	43 (26.9)	
40–45 years	251 (72.3)	96 (27.7)	
>45 years	128 (71.1)	52 (28.9)	
Doctor's cesarean section rate (%)	16.3 ± 2.7	16.8 ± 2.6	0.008

IUFGR intrauterine fetal growth restriction, *PROM* premature rupture of membranes, *BMI* body mass index, *FHR* fetal heart rate

t test for qualitative or quantitative variables, respectively. Of these variables, associations with P values of <0.25 were chosen to be included in the multivariate binary logistic regression model [22]. This model was constructed by using backward elimination (random variables in SPSS). Next, the predictive ability was studied by means of a receiver-operating characteristic (ROC) curve (Table 1).

From among the eligible models, those that best fulfilled the following characteristics were chosen: suitable calibration (Hosmer–Lemeshow test), area under the ROC curve (AUC), parsimony (small number of explanatory variables), ease of interpretation, and clinical plausibility.

Two predictive models were created: model A predicts the outcome at the time the woman is admitted to the hospital (before the decision on the method of induction); and model B predicts the outcome at the time the woman is officially admitted to the labor room (Table 2; Fig. 2).

Then the individual predictive ability of each predictor that formed the models A and B was studied and the predictive ability was studied across different subgroups: previous cesarean section, use or not of prostaglandins, and the main reasons for induction (diabetes, post-term pregnancy (PTP), and PROM) (Table 3).

Due to the possible absence of some predictor depending on the workplace, different predictive models were devised with different combinations of the predictors of model B, calculating for each one of them their AUC of ROC (Table 4).

Lastly, the following were determined from model B: sensitivity, specificity, positive predictive values (PPV), negative predictive values (NPV), positive likelihood ratio (+LR), and negative likelihood ratio (−LR) for the risk of cesarean section and vaginal delivery of different estimated probabilities (Table 5).

SPSS 20.0 was used for the statistical analysis.

Results

After applying the exclusion criteria, the study population consisted of 841 subjects, 704 (84.3 %) of whom were used in the construction of the predictive model. Figure 1 shows the screening process.

The variables related to labor outcome (*P* values <0.25) and eligibility to be included in the initial model were: overall and categorized maternal height, overall and categorized BMI, parity, overall and categorized gestational age, previous cesarean section, previous induction, use of prostaglandins, Bishop score, oligohydramnios, fertility treatment, overall and categorized weight of newborn, gender of fetus, and gynecologist's age and cesarean section rate. Table 2 shows the univariate analysis.

Next, the multivariate analysis was performed, with model A and model B consisting of the following variables: categorized maternal height, categorized BMI, parity, Bishop score, categorized gestational age, macrosomia, gender of the fetus and cesarean section rate of the gynecologist in charge. The Bishop score was different between the two models depending on the obstetric assessment at the corresponding time. The models are shown in Table 3.

The AUC for model A was 0.77 (95 % CI 0.73–0.80), and for model B 0.79 (95 % CI 0.76–0.83) (Fig. 2).

Subsequently, the individual predictive ability of the variables that formed models A and B was studied. It was

Table 2 Predictive models for risk of cesarean section with multivariate analysis

Predictor	Labor outcome			
	Coefficient B	Odds ratio	95 % CI	*P* value
Model A: Hospital admission				
Height <170	0.790	221	1.20–4.01	0.011
BMI (reference category <25)				
25–29.9	0.588	1.80	1.19–2.70	0.005
≥30	0.809	2.25	1.23–3.78	0.002
Nulliparity	1.651	5.21	2.45–8.36	<0.001
Bishop score at hospital admission	−0.230	0.791	0.72–0.88	<0.001
Gestational age (reference category 37–41)				
<37	1.012	2.75	1.41–5.35	0.005
≥41	0.390	1.49	0.95–2.30	0.084
Macrosomia ≥4000	1.260	3.53	1.32–9.45	0.012
Gender of newborn: male	0.333	1.40	0.97–2.11	0.075
Doctor's cesarean section rate (%)	0.057	1.06	1.03–1.09	<0.001
Logarithm to estimate cesarean section risk	−4.687 + 0.790 × Height <1.70 + 0.588 × BMI (25–29.99) + 0.790 × BMI (≥30) + 1.651 × parity (0 = multiparous and 1 = nulliparous) − 0.230 × Bishop (score) + 1.012 × gestational age (<37 weeks) + 0.390 × gestational age (≥41 weeks) + 1.260 × macrosomia + 0.333 × gender: male + 0.057 × gynecologist's cesarean section rate in %			
Model B: onset of dilation				
Height <170	0.846	2.33	1.25–4.36	0.008
BMI (reference category <25)				
25–29.9	0.564	1.76	1.15–2.69	0.009
≥30	0.814	2.26	1.33–3.84	0.003
Nulliparity	1.730	5.64	3.49–9.13	<0.001
Bishop score at admission to labor room	−0.296	0.74	0.68–0.81	<0.001
Gestational age (reference category 37–41)				
<37	0.901	2.46	1.25–4.84	0.009
≥41	0.401	1.49	0.95–2.35	0.082
Macrosomia ≥4000	1.285	3.62	1.34–9.77	0.011
Gender of newborn: male	0.402	1.40	1.03–2.18	0.037
Doctor's cesarean section rate (%)	0.051	1.05	1.03–1.08	<0.001
Logarithm to estimate cesarean section risk	−3.827 + 0.846 × Height <1.70 + 0.564 × BMI (25–29.99) + 0.814 × BMI (≥30) + 1.730 × parity (0 = multiparous and 1 = nulliparous) − 0.296 × Bishop (score) + 0.901 × gestational age (<37 weeks) + 0.401 × gestational age (≥41 weeks) + 1.285 × macrosomia + 0.402 × gender: male + 0.051 × gynecologist's cesarean section rate in %			

Table 3 Predictive ability of risk of cesarean section of all the predictors that make up the models A and B individually and for various subgroups

	Predictive ability		
	AUC	95 % CI	*P* value
Predictors			
Height	0.54	0.49–0.58	0.107
BMI	0.56	0.52–0.61	0.009
Nulliparity	0.65	0.61–0.68	<0.001
BS hospital admission	0.63	0.59–0.67	<0.001
BS labor room	0.67	0.63–0.72	<0.001
Gestational age	0.55	0.51–0.59	0.025
Macrosomia	0.52	0.48–0.50	0.366
Gender of newborn	0.55	0.50–0.59	0.044
Doctor's cesarean section rate (%)	0.60	0.56–0.64	<0.001
Subgroup			
Previous cesarean section			
Model A	0.79	0.64–0.94	0.004
Model B	0.80	0.65–0.96	0.002
Use of prostaglandins			
Model A	0.76	0.71–0.81	<0.001
Model B	0.82	0.78–0.86	<0.001
No use of prostaglandins			
Model A	0.78	0.73–0.84	<0.001
Model B	0.73	0.67–0.80	<0.001
Induction (PROM)			
Model A	0.72	0.64–0.80	<0.001
Model B	0.70	0.62–0.79	<0.001
Induction (PTP)			
Model A	0.73	0.63–0.83	<0.001
Model B	0.79	0.69–0.88	<0.001
Induction (diabetes)			
Model A	0.85	0.78–0.91	<0.001
Model B	0.88	0.82–0.94	<0.001

AUC area under the curve, *95 % CI* 95 % confidence interval, *BMI* body mass index, *BS* Bishop score, *PROM* premature rupture of membranes, *PTP* post-term pregnancy

found that the BS in dilation [AUC = 0.65 (95 % CI 0.61–0.68)] and nulliparity [AUC = 0.63 (95 % CI 0.59–0.67)] were the ones that presented a greater capacity of prediction (Table 3).

The predictive ability of the models was then studied for the subgroups. Both models showed good predictive ability across all subgroups, particularly in previous cesarean sections and diabetes (Table 3).

In addition, several prediction models with different combinations of predictors were developed, excluding those variables with the greatest likelihood of non-availability in all the centers (Table 4). When the rate of cesarean section of the gynecologist was omitted (model 1), the predictor with greater risk of not being known, a predictive ability of 0.78 (95 % CI 0.74–0.82) was presented.

Finally, we studied the predictive characteristics for models A and B and found that for an estimated probability of cesarean section of ≥80 %, a +LR for cesarean section of 22.0 and 19.5, respectively, was observed. Also, a likelihood of estimated cesarean section ≤10 % presented a +LR for vaginal delivery of 13.7 and 6.3, respectively (Table 5).

Comment

In our study, we developed two models for predicting the risk of cesarean section in pregnant women after LI. Model A determines the risk at the time of hospital admission and model B at the time the woman is officially admitted to the labor room, with an ability to predict correctly in 0.76 and 0.79 of cases, respectively. The creation of these models for two different points of the LI process allowed us to verify the reliability of the variables used as predictors; something which had not been done before. Moreover, the model showed good predictive ability in the different subgroups studied, with the result for the previous cesarean section group at 0.79 and 0.80, respectively, of particular interest in terms of clinical utility, because many of these pregnant women prefer an elective cesarean.

With regard to the diagnostic characteristics, we can say that the models show excellent values for specificity, PPV and +LR for the cutoff points studied. The predictions are especially good for cesarean section when the odds are greater than 80 % and vaginal delivery when the likelihood of cesarean section is less than 10 %.

In this sense, although there are many works that attempt to predict the result of childbirth, only have been localized in these past 10 years, 9 models that incorporate in predicting other different variables to the BS and the length of the cervix by ultrasonography or in combination with these [13–21].

Of these, the model of Smith et al. [20] included nulliparous women and employed prostaglandins, and that of Isono et al. [16] included only low-risk nulliparous women, with an AUC of ROC of 0.67 and 0.73, respectively. Rane et al. created two models, one published in 2004 [19] and another in 2005 [18], without elaborating ROC curves, although subsequently Verhoeven et al. [23] validated this last one obtaining an AUC of 0.63. Cnattingus et al. [14] and Gomez-Laencina et al. [15] also created their own models, but did not provide the values of prediction of these. Only Cheung et al. [13], Pitarello et al. [21], and Peregrine et al. [17] presented models with capacities similar to ours, with AUC-ROC of 0.79, 0.80 and 0.83. But eventually, the model

Table 4 Predictive ability and coefficients of the predictors present to estimate the risk of cesarean section of different alternative models to model B in the absence of the some predictor

	C	Predictors usually available (coefficients)					Predictors potentially unavailable (coefficients)					Prediction ability of ROC curve area	
		Parity	Bishop	Height	BMI		GA		Macrosomia	Fetal sex	GCR	AUC	95 % CI
					25–29.9	≥30	<37	≥41					
Model 1 without GCR	−2.313	1.739	−0.302	0.887	0.555	0.759	0.832	0.408	1.299	0.457		0.78	0.74–0.82
Model 2 without fetal sex	−3.675	1.731	−0.291	0.810	0.568	0.817	0.925	0.403	1.380		0.054	0.79	0.75–0.83
Model 3 without fetal weight	−3.547	1.665	−0.296	0.827	0.556	0.783	0.860	0.498		0.442	0.051	0.79	0.75–0.83
Model 4 without GA	−3.547	1.669	−0.301	0.841	0.527	0.833			1.344	0.413	0.050	0.79	0.75–0.82
Model 5 without GCR and fetal sex	−2.062	1.737	−0.295	0.841	0.558	0.762	0.854	0.406	1.354			0.77	0.74–0.81
Model 6 without GCR and fetal weight	−2.237	1.672	−0.303	0.875	0.551	0.729	0.793	0.509		0.494		0.78	0.74–0.81
Model 7 without GCR and GA	−2.089	1.688	−0.303	0.887	0.521	0.781			1.334	0.462		0.77	0.73–0.81
Model 8 without GCR, sex and fetal weight and GA	−1.740	1.630	−0.297	0.836	0.520	0.748						0.76	0.73–0.80

ROC receiver-operating characteristic, *C* constant, *GCR* gynecologist cesarean rate, *GA* gestational age, *AUC* area under the curve, *95 % CI* 95 % confidence interval

Table 5 Predictive characteristics for cesarean section and vaginal delivery of the models A and B

	Sensitivity	Specificity	PPV	NPV	+LR	−LR
Model A						
Risk for cesarean section						
Probability ≥ 0.90	0.5	100	100	70.8	NC	0.95
Probability ≥ 0.80	4.4	99.8	90.0	71.6	22.0	0.96
Probability ≥ 0.70	9.7	99.2	83.3	72.6	12.1	0.91
Risk for vaginal delivery						
Probability ≤ 0.30	68.0	69.4	84.3	47.4	2.3	0.46
Probability ≤ 0.20	51.5	84.0	88.6	41.8	3.2	0.58
Probability ≤ 0.10	25.4	98.1	96.9	39.3	13.4	0.76
Model B						
Risk for cesarean section						
Probability ≥ 0.90	2.4	99.8	83.3	71.2	12.0	0.98
Probability ≥ 0.80	7.8	99.6	88.9	72.3	19.5	0.93
Probability ≥ 0.70	15.5	98.4	80.0	73.8	9.7	0.86
Risk for vaginal delivery						
Probability ≤ 0.30	69.4	73.3	86.2	49.8	2.6	0.42
Probability ≤ 0.20	54.3	82.5	88.2	42.8	3.1	0.55
Probability ≤ 0.10	30.6	95.1	93.8	36.2	6.3	0.73

NC not calculated, *PPV* positive predictive value, *NPV* negative predictive value, *+LR* positive likelihood ratio, −LR negative likelihood ratio

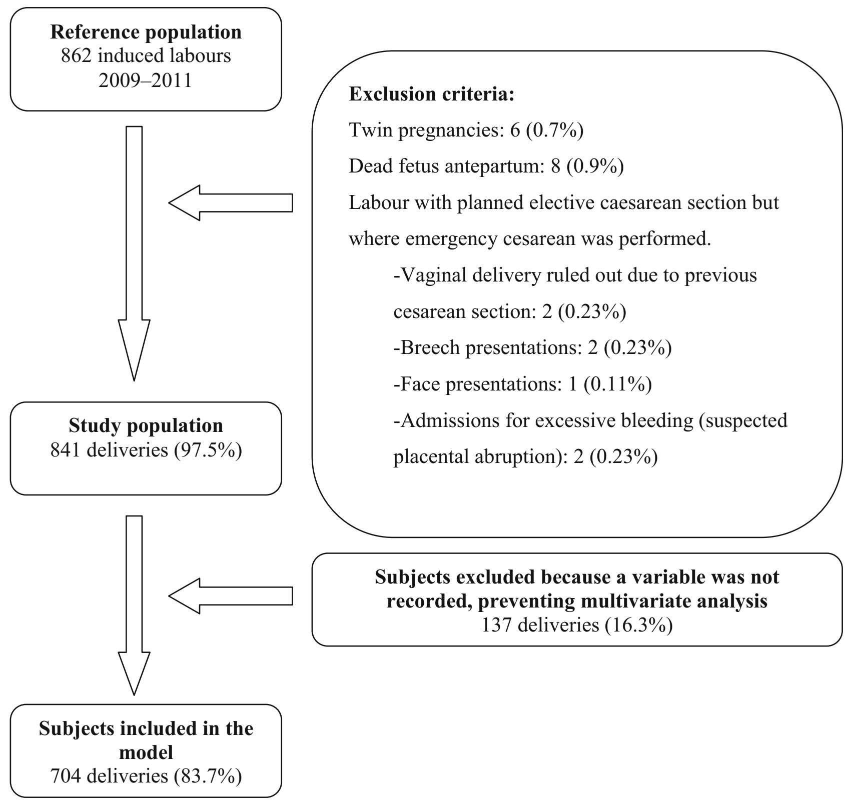

Fig. 1 Screening process and exclusion criteria

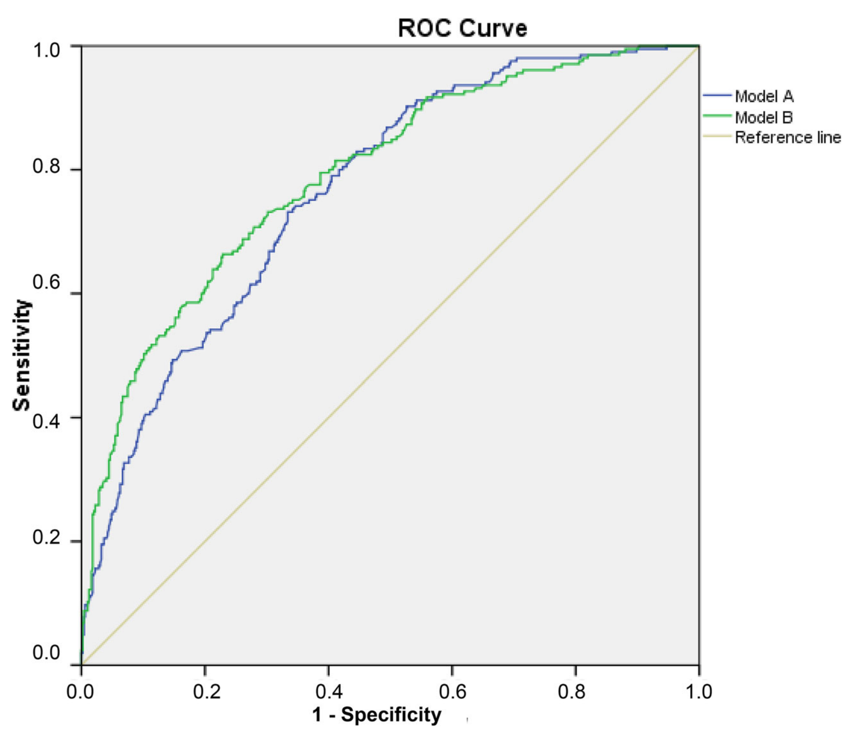

Fig. 2 ROC curves of predictive models *A* and *B*

of Peregrine et al. was validated by Verhoeven et al. [23] and by Bertossa et al. [24] and its predictive capacity was reduced to 0.76 and 0.59, respectively.

In our study, in both model A and model B, the variables used were: categorized maternal height, categorized BMI, parity, Bishop score, categorized gestational age, macrosomia, gender of fetus, and gynecologist's average individual cesarean section rate.

With regard to the factors that make up the model, we found that maternal height [13, 15–17, 21], BMI [14, 15, 17–19] and gestational age [18, 21] were incorporated into their models by several authors, although with different cutoff points according to the study.

Another predictor employed and of great significance in the various types of work was the parity [13–15, 17–19, 21]. We found in our case that pregnant nulliparous women presented a likelihood of a cesarean section in the adjusted model five times greater than multiparous women.

In spite of this, the employment of the BS to assess the cervix, at admission to the hospital and at the onset of the dilation factor was considered the most important predictor. This test was also employed in other models of IDP [13, 15, 16, 21], but was replaced or supplemented in other studies by certain measurements of the cervix by ultrasonography [13, 15, 17–19, 21]. In this respect, we believe that models that incorporate Bishop score as opposed to sonographic measurement of the cervix are more likely to be used and validated. Although this is not considered a good predictor of labor per se, it can be used in all circumstances. The measurement of cervical length, however, requires suitable training and equipment. In addition, there is no evidence of the superiority of the ultrasound measurement against the BS [25]. Since Hatfiel et al. [11] and Verhoeven et al. [12] published systematic reviews in 2007 and 2013, respectively, it was concluded that measurement by ultrasonography of the cervix was not a good predictor of the outcome of childbirth. Besides, a Canadian Guide of Clinical Practice currently continues recommending the appraisal of BS in pre-induction [26].

Based on the fetal factors included in the model, we found a relationship between the risk of cesarean section and macrosomia, although this predictor was only employed in the model of Isono et al. [16].

With regard to fetal sex, only the model of Smith et al. [20] took it into account. In our study, male fetus was 7.6 % more likely to present the risk of cesarean section than female fetus. This finding is arguably due to the females' higher capacity to adapt to the stress of labor, as various studies have shown [27–29].

One of the most important aspects of our study is that it is the first to incorporate the responsible gynecologist's cesarean section rate as a predictor. The likelihood of labor is also conditioned to a large extent by factors related to health care or health-care professionals. These factors may contribute to the large variability in the performance of cesarean sections among countries, centers and even professionals within a unit [30–32]. Therefore, any model that does not take this source of variability into account may be incomplete. This aspect constitutes both the primary strength and weakness of the study. It is a strength because, by considering this rate, we can see that this model has been used at other centers with different health-care characteristics; it is a weakness because the gynecologist's cesarean section rate may not be available, although in this case it could be replaced by the rate for the center. To overcome this obstacle, we have elaborated various alternative models omitting different predictors, considering the possibility that this information may not be available in the workplace so that it can be applied in a major number of circumstances (Table 5).

We recognize as a limitation that for this predictive model to be of potential use, it must first be validated at our center with a cohort other than that used to construct the model and then again at other centers.

In spite of this, we believe that models have a good ability to predict the risk of cesarean section and they may be a useful tool to aid decision making.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest and that this study has been conducted with no funding.

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