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A predictive model for successfully inducing active labor among pregnant women: Combining cervical status assessment and clinical characteristics

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ABSTRACT

Objective: To develop a predictive model for successfully inducing active labor by using a combination of cervical status and maternal and fetal characteristics.
Study design: A retrospective cohort study was conducted among pregnant women who underwent labor induction between January 2015 and December 2019. Successfully inducing active labor was defined as achieving a cervical dilation > 4 cm within 10 h after adequate uterine contractions. The medical data were extracted from the hospital database; statistical analyses were performed using a logistic regression model to identify the predictors associated with the successful induction of labor. The receiver operating characteristic (ROC) curve and area under the curve (AUC) were used to assess the accuracy of the model.
Results: In total, 1448 pregnant women were enrolled; 960 (66.3 %) achieved successful induction of active labor. Multivariate analysis revealed that maternal age, parity, body mass index, oligohydramnios, premature rupture of membranes, fetal sex, dilation, station, and consistency were significant factors associated with successful labor induction. The ROC curve of the logistic regression model had an AUC of 0.7736. For the validated score system to predict the probability of success, we found that a total score > 60 has a 73.0 % (95 % CI 59.0–83.5) probability of successful induction of labor into the active phase stage within 10 h.
Conclusions: The predictive model for successfully achieving active labor using the combination of cervical status and maternal and fetal characteristics had good predictive ability.

Introduction

Labor induction is a common obstetric procedure that has gradually increased in incidence to approximately 20 % of pregnancies [1,2]. Our institution has a similar rate, wherein 10–15 % of pregnancies require labor induction [3]. Induction is typically indicated when the benefit to the mother and/or fetus outweighs the continuation of pregnancy; it may be initiated by physical (amniotomy) or pharmacological (prostaglandin drugs and/or oxytocin) methods depending on the initial Bishop score assessment [4]. Important concerns regarding this common procedure include the adverse outcomes associated with a prolonged latent phase of labor, which have been reported to increase the risk of chorioamnionitis (from 20–22 % to 25–27 %) and postpartum hemorrhage (from 11 % to 16 %) after 6 and 12 h in the latent phase, respectively [5,6]. Additionally, some patients, particularly nulliparous women, undergo cesarean delivery owing to dystocia and/or fetal distress after labor induction [7,8].

The criteria for successful and failed labor induction have not been standardized, and no consensus has been reached; however, several studies reported various interesting endpoints of this procedure. Most studies focused on predicting vaginal or cesarean delivery using cervical assessments alone (Bishop score and/or transvaginal ultrasound) [9–11] or by combining maternal and fetal factors [12–21]. Many risk factors are proposed to be associated with cesarean delivery, including an unfavorable cervix, greater body mass index (BMI), shorter maternal height, pregestational diabetes, gestational diabetes, nulliparity, and advanced maternal age [9,18,19,22]. Although predictive models have been developed to predict the risk for cesarean delivery after labor induction, their use in clinical practice is not recommended owing to their moderate predictive capacity [10,16,17,23].

Few previous studies on failed labor induction reported the inability to achieve active labor—defined as a cervical dilation < 4–5

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cm—despite adequate exposure to cervical priming and oxytocin stimulation [24–30]. These studies reported that clinical risk factors had a low predictive value when used in clinical practice, with only the cervical status (Bishop score) remaining an important predictor of successful induction of active labor. The study using a combination of maternal and fetal factors for prediction of successfully induced active labor was limited. Therefore, this study aimed to construct a predictive model for the successful induction of active labor using a combination of cervical status, maternal and fetal characteristics in order to increase the predictive value.

Materials and methods

This retrospective cohort study was conducted at Songklanagarind Hospital, a tertiary center in Southern Thailand. This study was approved by the Ethics Committee of the Faculty of Medicine, Prince of Songkla University (No. 62–445–12–4) in January 2020. Access and use of the medical records of all participants were permitted by the medical director of Songklanagarind Hospital. The ethics committee waived the requirement for informed consent.

We reviewed the medical records of all pregnant women who underwent labor induction between January 2015 and December 2019 by extracting data from the hospital database's computerized medical records system. Exclusion criteria were gestational age less than 36 weeks, abnormal fetus presentation, stillbirth, or cesarean delivery owing to fetal distress or worsening maternal condition before a cervical dilation of 4 cm and 10 h of regular uterine contraction.

Labor was induced according to the standard protocol. Patients with an unfavorable cervix (Bishop score <7) received a prostaglandin E2 vaginal suppository; labor was then augmented using oxytocin at a starting dose of 6 mU/min with a 1-mU/min increase every 15 min until a regular uterine contraction was achieved (200–225 Montevideo Units or 3 contractions/10 min). The primary outcome was successfully achieving active labor through induction. Because there is no standard definition or consensus regarding the timing or diameter of cervical dilation to establish a failure to induce active labor in these patients, our study defined the inability to achieve active labor as a cervical dilation of < 4 cm within 10 h despite adequate uterine contraction.

To develop a predictive model for the successful induction of active labor, we retrieved and evaluated all maternal characteristics that could be associated with the outcome, including maternal age, gravidity, parity, abortion, gestational age at delivery, pre-pregnancy weight, height, weight gain by gestational age, underlying disease (such as hypertension and diabetes mellitus), antepartum complications (gestational hypertension, preeclampsia, oligohydramnios, fetal growth restriction, and premature rupture of membranes (PROM)), and indications for labor induction. Fetal characteristics, including birth weight and sex, were evaluated, and cervical assessments were conducted to obtain the Bishop score according to the five usual criteria [4].

Statistical analysis

The statistical analyses were performed using R v. 3.6.3 (R Core Team, 2020) and Stata v.14.2 (StataCorp LLC, College Station, TX, USA). Demographic and pregnancy-related characteristics are summarized using numbers and percentages and compared between successful and unsuccessful labor inductions; differences between the groups were evaluated using the chi-squared test. To develop a predictive model for successful induction, all relevant maternal and fetal variables were initially entered into a logistic regression model using R software and the best-fit model, as reflected by the minimum determined Akaike information criterion value. The model was then further reduced by sequentially removing weakly associated variables ($P > 0.05$) with successful induction, reflected by the change in log-likelihood.

A receiver operating characteristic (ROC) curve was constructed, and the area under the curve (AUC) was examined at each modeling stage. Based on the coefficients of this model, an integer value score was allocated to each level of each predictor such that the ratios among the scores approximated the ratios among the coefficients. An overall score to predict successful labor induction was then constructed based on the summary of individual variable-level scores for each pregnant woman. The predicted probability of successful induction and its 95 % confidence interval (CI) were extracted from the model, and the relationship between the overall score and the model for the probability of success was graphically expressed. The validity of the model was tested and checked for over-optimism bias in two ways: first, by using 1000 bootstrap resamples; and second, by splitting the sample into training and test datasets in a 2:1 ratio.

Results

In total, 1448 women who underwent labor induction were enrolled in the study; among them, labor was successfully induced in 960 women (66.3 %). These successfully induced women had normal vaginal delivery 447 cases (46.6%), instrumental vaginal delivery 270 cases (28.1 %) and the remaining women had cesarean delivery (25.3 %). The median time from induction to vaginal delivery was 600 (IQR: 368–854) minutes. The fail induced group, all had cesarean delivery with median time from induction to cesarean delivery was 905 (IQR: 540–1073) minutes. As shown in Table 1, pregnant women who were successfully induced were more likely to be multiparous; use prostaglandins for induction; and have lower BMI, oligohydramnios, PROM, lower fetal birth weight, fetal female sex, and more favorable cervical examination (dilation, effacement, station, consistency, position, and Bishop score) results.

Table 2 shows the results of the multivariate analysis of factors associated with successful labor induction. Maternal age, parity, BMI, oligohydramnios, PROM, fetal sex, cervical dilation, station, and consistency were significant factors. We assumed that increasing maternal age would be associated with increasing parity; thus, the two factors were merged to analyze the parity-age association. Fig. 1 presents the ROC curve from the logistic regression model with an AUC of 0.7736 (95 % CI 0.7494–0.7977). Bootstrap resampling yielded a median value of 0.7693 (2.3 and 97.5 percentiles: 0.7440, 0.7940), and the test sample yielded an AUC of 0.7569 (95 % CI 0.7132–0.8005). Thus, the validation values were only slightly lower than that of the original model.

The score allocation derived from the multivariable logistic regression analysis to predict the probability of successfully inducing labor with 95% CI is shown in Tables 3 and 4. We found that a total score of > 60 had a 73% (95% CI: 59.0–83.5) probability of successfully inducing active labor within 10 h.

Discussion

This study aimed to assess factors associated with achieving active labor among patients with induced labor. Our results revealed that a combination of cervical factors (dilation, station, and consistency) and clinical characteristics (maternal age, parity, BMI, oligohydramnios, PROM, and fetal sex) had a good predictive ability, with an AUC of 0.7736. We then constructed a validated scoring system to predict the probability of success and found that patients with a total score > 60 had a 73 % (95 % CI: 59.0–83.5) chance of reaching active labor within 10 h.

As no consensus regarding the criteria for failed labor induction has been reached to date, most reports defined failed labor induction as the inability to achieve a cervical dilation of > 4 cm after 12 + 3 h of regular uterine contraction; this was based on a concern for adverse outcomes, especially after 12 h of induction [24–31]. Our study defined the inability to achieve active labor as a cervical dilation of < 4 cm within 10 h despite adequate uterine contraction. Based on data from our cohort, the median time from labor induction to successful vaginal delivery was 600 min according to the aforementioned definition. Furthermore, the outcome of this procedure for most studies was the

Table 1
Demographic data.

	Success (n = 960)	Failed (n = 488)	P-value*
Age			0.315
1 (<20 years)	25 (2.6 %)	7 (1.4 %)	
2 (20–34.9 years)	692 (72.1 %)	362 (74.2 %)	
3 (>35 years)	243 (25.3 %)	119 (24.4 %)	
Parity			< 0.001
0	604 (62.9 %)	459 (94.0 %)	
1	251 (26.2 %)	18 (3.7 %)	
> 2	105 (10.9 %)	11 (2.3 %)	
Gestational age at induction			0.122
36	3 (0.3 %)	0 (0 %)	
37	95 (9.9 %)	37 (7.6 %)	
38	190 (19.8 %)	79 (16.2 %)	
39	284 (29.6 %)	147 (30.1 %)	
40	333 (34.7 %)	196 (40.2 %)	
41	52 (5.4 %)	29 (5.9 %)	
42	3 (0.3 %)	0 (0 %)	
Height			0.058
< 155 cm	272 (28.3 %)	163 (33.4 %)	
155–160 cm	378 (39.4 %)	164 (33.6 %)	
> 160 cm	310 (32.3 %)	161 (33.0 %)	
BMI			< 0.001
< 18.5	119 (12.4 %)	36 (7.4 %)	
18.5–22.9	470 (49.0 %)	222 (45.5 %)	
> 23	371 (38.6 %)	230 (47.1 %)	
Gestational weight gain			0.272
< 10 kg	190 (19.8 %)	81 (16.6 %)	
10–19.9 kg	669 (69.7 %)	348 (71.3 %)	
> 20 kg	101 (10.5 %)	59 (12.1 %)	
Chronic hypertension			0.053
No	920 (95.8 %)	478 (98.0 %)	
Yes	40 (4.2 %)	10 (2.0 %)	
Gestational hypertension			0.462
No	924 (96.2 %)	465 (95.3 %)	
Yes	36 (3.8 %)	23 (4.7 %)	
Preeclampsia			0.941
No	925 (96.4 %)	469 (96.1 %)	
Yes (without severe feature)	16 (1.7 %)	8 (1.6 %)	
Yes (with severe feature)	19 (1.9 %)	11 (2.3 %)	
Diabetes mellitus			0.252
No	946 (98.5 %)	476 (97.5 %)	
Yes	14 (1.5 %)	12 (2.5 %)	
Oligohydramnios			0.018
No	768 (80.0 %)	416 (85.2 %)	
Yes	192 (20.0 %)	72 (14.8 %)	
Fetal growth restriction			0.111
No	914 (95.2 %)	474 (97.1 %)	
Yes	46 (4.8 %)	14 (2.9 %)	
Premature rupture of membranes			0.034
No	791 (82.4 %)	424 (86.9 %)	
Yes	169 (17.6 %)	64 (13.1 %)	
Induction medication			< 0.001
Oxytocin	274 (28.5 %)	152 (31.2 %)	
PGE2	429 (44.7 %)	104 (21.3 %)	
Both	257 (26.8 %)	232 (47.5 %)	
Birth weight			0.018
< 2500 g	49 (5.1 %)	19 (3.9 %)	
2500–2999 g	270 (28.1 %)	120 (24.6 %)	
3000–3499 g	435 (45.3 %)	209 (42.8 %)	
> 3500 g	206 (21.5 %)	140 (28.7 %)	
Fetal sex			0.003
Male	435 (45.3 %)	262 (53.7 %)	
Female	525 (54.7 %)	226 (46.3 %)	
Dilation			< 0.001
0 cm	300 (31.3 %)	273 (60.0 %)	
1 cm	438 (45.6 %)	168 (34.4 %)	
2 cm	222 (23.1 %)	47 (9.6 %)	
Effacement			< 0.001
0–30%	658 (68.5 %)	390 (79.9 %)	
40–50%	238 (24.8 %)	81 (16.6 %)	
60–70%	44 (4.6 %)	14 (2.9 %)	
> 80%	20 (2.1 %)	3 (0.6 %)	
Station			< 0.001
-3	202 (21.0 %)	150 (30.8 %)	
-2	574 (59.8 %)	287 (58.8 %)	
-1	162 (16.9 %)	47 (9.6 %)	
0	22 (2.3 %)	4 (0.8 %)	
Consistency			< 0.001
Firm	21 (2.2 %)	30 (6.2 %)	
Medium	68 (7.1 %)	44 (9.0 %)	
Soft	871 (90.7 %)	414 (84.8 %)	
Position			< 0.001
Posterior	227 (23.6 %)	142 (29.1 %)	
Middle + anterior	733 (76.4 %)	346 (70.9 %)	
Bishop score			< 0.001
0–2	102 (10.6 %)	93 (19.1 %)	
3–5	536 (55.8 %)	307 (62.9 %)	
6–9	332 (34.6 %)	88 (18.0 %)	

*chi-squared test

Table 2
Predictors for successful achievement of the active phase of labor within 10 h AFter Adequate Uterine Contractions (Final Model).

	Odds ratio	95% Confidence interval	P-value[a]
Parity-age			< 0.001
Nulliparous < 25 years	1.64	1.00–2.74	
Nulliparous 25–34.9 years	1.26	0.87–1.83	
Nulliparous > 35 years	Reference		
Parous < 25 years	6.66	2.14–20.75	
Parous 25–34.9 years	23.41	11.23–48.82	
Parous > 35 years	8.92	4.58–17.36	
BMI			< 0.001
< 18.5	2.64	1.69–4.13	
18.5–22.9	1.71	1.32–2.29	
> 23	Reference		
Oligohydramnios			0.039
Yes	1.43	1.02–2.00	
No	Reference		
Premature rupture of membranes			0.033
Yes	1.46	1.03–2.07	
No	Reference		
Fetal sex			0.008
Male	Reference		
Female	1.39	1.09–1.78	
Dilation			< 0.001
0 cm	Reference		
1 cm	1.83	1.39–2.42	
2 cm	2.49	1.65–3.75	
Station			0.017
-3	Reference		
-2	1.20	0.89–1.62	
-1	1.57	0.99–2.47	
0	2.69	0.86–8.47	
Consistency			0.041
Firm	Reference		
Medium + soft	1.96	1.02–3.79	

[a] Likelihood ratio test

route of delivery; few studies have focused on successfully achieving active labor. Similar to the results of our study, cervical status has been reported to be a significant predictor of successfully inducing active labor [24,26–30]; however, when using cervical status alone, the likelihood of a successful prediction was less than that when using a combination of cervical status and clinical characteristics. Multiparity and lower maternal weight were previously reported to be factors for a higher likelihood of successfully inducing active labor when combined with the cervical status assessment [24,29]; this was also observed in our study. In addition, we identified that oligohydramnios, PROM, and female fetuses were positive predictive factors for entering active labor.

In our study, female infants (3181 g [95 % CI: 3151–3211]) had a

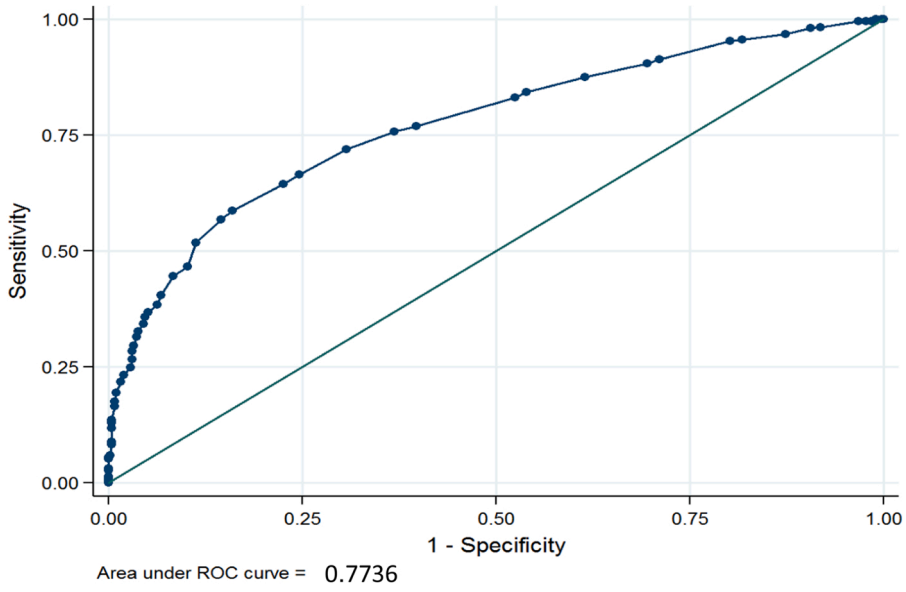

Fig. 1. Receiver operating curves (ROC) demonstrating the predictive ability of the regression model from combining the significant maternal characteristics, cervical, and fetal factors.

Table 3
Summary of Individual Variable-level Scores (Total Score: 127 Points).

	Coefficient	Score[a]
Parity-age		
Nulliparous < 25 years	0.501	4
Nulliparous 25–34.9 years	0.231	2
Nulliparous > 35 years	-	0
Parous < 25 years	1.897	17
Parous 25–34.9 years	3.153	28
Parous > 35 years	2.188	19
BMI		
< 18.5	0.972	9
18.5–22.9	0.538	5
> 23	-	0
Oligohydramnios		
Yes	0.355	3
No	-	0
Premature rupture of membrane		
Yes	0.377	3
No	-	0
Fetal sex		
Male	-	0
Female	0.331	3
Dilation		
0 cm	-	0
1 cm	0.606	5
2 cm	0.911	8
Station		
-3	-	0
-2	0.184	2
-1	0.448	4
0	0.991	9
Consistency		
Firm	-	0
Medium + soft	0.675	6

BMI, body mass index
[a] Each score is derived from the coefficient multiplied by 8.8

Table 4
Estimated probabilities of successful induction according to the allocated score with a 95 % confidence interval.

Score	Estimated probability of success (%)	95% Confidence interval
0–9	53.3	44.9–61.6
10–19	58.0	53.0–62.9
20–29	64.5	61.7–67.3
30–39	69.5	65.2–73.4
40–49	71.8	64.7–78.0
50–59	72.7	62.3–81.1
> 60	73.0	59.0–83.5

lower mean birth weight than male infants (3219 g [95 % CI: 3187–3251]). Our results were similar to those of a previous report showing that pregnant women with male fetuses had more cesarean deliveries owing to failure to progress due to the larger size of male fetuses [32]. In addition to the difference in weight between male and female infants, the head circumference of female fetuses was smaller than that of males [32,33]. Moreover, we found that only dilation, station, and consistency (parameters of the Bishop score) were significantly associated with success. Previous reports also showed that not all parameters of the Bishop score were associated with the prediction of vaginal delivery (only dilation, effacement, and station were significant) [9,13] and proposed using a simplified Bishop score, rather than the original score, for ease of use in clinical practice [9,18].

When we compared risk factors associated with inducing active labor and cesarean delivery, we found that several factors had consistent outcomes. Pregnant women with nulliparity, advanced age, higher BMI, and poorer cervical status also exhibited risks for slow progression into the active phase of labor and cesarean delivery [10,12,14–16,18,20–22]. Some previous reports revealed that patients with advanced maternal age had less robust vasculature and an insufficient hemodynamic demand during pregnancy, which may lead to a gradual decrease in myometrial contraction function [34,35]. Furthermore, patients with advanced age and/or high BMI demonstrated a higher incidence of complications—such as preeclampsia, gestational diabetes, and fetal macrosomia—that necessitated cesarean delivery owing to dystocia or nonreassuring fetal status [12,14,19]. Several other clinical factors (maternal height, gestational weight gain, chronic hypertension, diabetes, abruptio placenta, and fetal growth restriction) were reported to indicate an increased probability of cesarean delivery among labor-induced patients [16,20–22] and among those experiencing spontaneous labor [36]. Therefore, recent reports [20,21] have proposed models or validated scores to predict cesarean and vaginal deliveries after labor induction using multiple significant risk factors that can be of practical use in patients undergoing labor induction. These had good predictive ability overall (AUC: 0.74–0.81).

We developed a model to predict the successful achievement of active labor in labor-induced patients, with a good predictive ability (AUC: 0.7728). We found that several previously stated factors associated with cesarean delivery did not affect the achievement of active labor [16,20–22]; however, avoiding labor induction in pregnant women with these risk factors is unlikely to be an efficient method to prevent their first cesarean delivery. Therefore, we proposed using a combination of models to predict the successful achievement of active labor and cesarean/vaginal deliveries among labor-induced patients in clinical practice. Counseling these patients could help them decide whether to continue with the induction process or undergo a cesarean delivery based on the probability of successfully entering the active phase of labor. It could also help identify the need for cesarean delivery without increasing the adverse outcomes associated with a prolonged latent phase of labor.

However, an important limitation of our study was the duration used to define success (10 h after regular and adequate uterine contractions), which we defined by using the median time of successful vaginal delivery among our cases. This was not defined according to standardized definitions for failed labor induction; therefore, other populations using this model should be aware of the different characteristics that could affect the timing of successful vaginal delivery. Furthermore, our prediction model focus on the chance of successfully induced to achieve active phase of labor, neither route of delivery nor risk of an emergency cesarean delivery following the induction process.

In conclusion, labor induction is a common obstetric procedure with specific clinical factors related to successfully achieving active labor. Our predictive model for successfully inducing active labor using a combination of cervical status and maternal and fetal characteristics showed good predictive ability.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Faculty of Medicine, Prince of Songkla University (No. 62–445–12–4). The medical director of Songklanagarind Hospital granted us privileges to access and use the medical records of all participants enrolled in this study.

Consent for publication

Not applicable.

Authors' contribution

CL was involved in project development, data collection, data analysis, and manuscript writing. NP aided with project development, data analysis, and manuscript writing. AG performed data analysis and helped with manuscript writing.

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Declaration of Competing Interest

The authors have no conflict of interest.

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