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Validating a predictive model for caesarean section in low-risk nulliparous pregnancies

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ABSTRACT

Problem: Caesarean birth (CS) rates are steadily increasing.
Background: In 2017 Janssen et al. developed a model which could predict CB in nulliparous healthy woman with 71 % accuracy based on factors measurable on admission to the hospital.
Aim: To validate the predictive model for risk of caesarean birth among low-risk, nulliparous women in a new setting.
Methods: A retrospective chart study in Abbotsford Regional Hospital (British Columbia, Canada) of healthy nulliparous women in spontaneous labour, at term, with a singleton fetus in cephalic position. Sociodemographic, pregnancy and labour-related characteristics were collected and independent predictors of CS were determined using multivariate logistic regression. The Janssen model was tested in the Abbotsford sample and additionally novel predictors were tested in an effort to improve the model. The area under the ROC curve (C-statistic) was computed and model calibration, sensitivity and specificity evaluated for the final model.
Findings and discussion: Of 348 women, 106 (30.5 %) had a CB. Applying the Janssen predictive model to the Abbotsford data resulted in a C-statistic of 0.77. No new predictors were added to the model. The mean predicted risk score for CS in the cohort was 0.30 ± 0.20. A risk score cut-off of 0.32 was determined resulting in a sensitivity and specificity of 69 %. The model had acceptable calibration.
Conclusion: A model with variables easily accessible at admission can predict caesarean birth in nulliparous women. The results from this study can guide provision of more intensive care during labour to women at higher risk, with the overall goal of reducing CB rates.

Statement of significance

Problem

Caesarean rates among nulliparous women are steadily increasing in Canada and other high resource countries.

What is already known

Caesarean births are associated with higher maternal and newborn morbidity.

What this paper adds

The risk of caesarean birth for healthy nulliparas at hospital admission can be predicted at hospital admission, thus identifying women who may benefit from targeted strategies to promote vaginal birth.

Introduction

Caesarean birth (CB) rates have increased steadily in Canada, to 31 % (30.8–31.2), in 2020 [1]. The World Health Organization has stated that

Abbreviations: CB, Caesarean Birth; BC, Province of British Columbia; BMI, Body Mass Index; OR, Odds Ratio; AUC, Area Under the Curve; ROC, Receiver Operating Characteristic.

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a cesarean section should only be performed when medically necessary and national CB rates of up to 19 % (but not above) have been associated with lower maternal and neonatal mortality [2]. Yet, worldwide, the annual rate of CB has almost doubled between 2000 and 2015 from 12.1 to 21.1 % [3]. A recent Lancet review of the health effects of CB reports that the prevalence of maternal mortality and severe maternal morbidity is higher after caesarean compared to vaginal birth due to higher risk of uterine rupture, abnormal placentation, ectopic pregnancy, stillbirth and preterm birth [4]. The ongoing rise of CB has been attributed in part to the effects of obesity, excessive weight gain during pregnancy, hypertension, multiparity and repeat CB as well as an increased use of induction of labour and fewer vaginal breech births [5–8]. The factors explaining the rise among apparently healthy women are not well understood. The leading medical indications for primary CB in this group are dystocia or prolonged labour, fetal distress and fetal malpresentation [8]. However, maternal risk factors giving rise to these indications have not been reliably identified.

The accurate prediction of risk for CB would enable the development and testing of new approaches to intrapartum care tailored to caesarean risk status. Identifying women at high risk for CB at admission would provide an opportunity to offer interventions aimed at promoting physiologic birth. Prediction of CB risk among low-risk, nulliparous women with spontaneous labour at admission, was demonstrated with 71 % accuracy by Janssen et al. [9] in British Columbia (BC), Canada. Factors that independently predicted CS included higher maternal age, shorter height, higher gestational age, maternal perception of onset of contractions > 24 h before admission, irregular contractions, lesser cervical dilatation and higher fetal station at admission. The purpose of the current study was to validate this predictive tool for risk of caesarean birth among low-risk, nulliparous women at term in spontaneous labour that could be utilized at hospital admission. We undertook our validation study at a regional hospital in BC providing 24 h maternity care, including caesarean section availability, to women not experiencing major antepartum complications. These women constituted our target group for use of our prediction tool.

Participants, ethics and methods

Study design

In this retrospective study of healthy nulliparous women, predictive factors for CB were examined with the goal of validating the model developed by Janssen et al. *(Janssen predictive model)* [9]. We also developed a new model testing novel predictors not previously available in the original study. The best performing model was then tested for calibration, discrimination and accuracy.

Setting

The study subjects were women giving birth at Abbotsford Hospital in the province of BC, Canada. This hospital was selected as a regional hospital with 24 h caesarean section availability and serving women without serious pregnancy complications. In BC, women experiencing healthy pregnancies may choose a midwife, family practice physician or, in urban centres, an obstetrician for primary maternity care. In rural areas, obstetricians provide consultant care.

Study sample

All hospital charts (from the period: February 1–December 31, 2017) of nulliparous women admitted to the birthing ward in spontaneous labour at term (week 37 +0–41 +6) with a singleton fetus in cephalic presentation were reviewed. Women with pre-existing health conditions including cardiac, renal, neurological, psychiatric, metabolic or other conditions that warranted treatment or increased surveillance during pregnancy were excluded. Women who had experienced conditions during pregnancy that warranted treatment or increased surveillance such as preeclampsia, gestational diabetes, pregnancy induced hypertension were also excluded. We restricted our sample to nulliparous women as parity is a strong effect modifier of CB. The major predictor of CB among multiparous women is a prior caesarean section ; among multiparous women with only previous vaginal births, CB rates are very low and should be studied separately from those of nulliparous women. Women who had requested elective CB and therefore refused vaginal birth when arriving to the hospital in spontaneous labour were excluded (n = 3) and as was a woman who had an unplanned home birth (n = 1) and women who presented with placental abruption (n = 2). Perinatal Services BC provided us with access to chart numbers for all women meeting our eligibility criteria giving birth in Abbotsford during the study time period. Perinatal Services BC hosts the Province of British Columbia Perinatal Registry, which holds hospital-submitted records of more than 99 % of births occurring in BC, Canada [10,11].

Sample size

The sample size required for model development was determined on the basis of the minimum standard of ten events per variable considered in the model according to the formula $N = (n \times 10)/I$ where N is the sample size, n is the number of candidate predictor variables, and I is the estimated event rate in the population [12]. An estimated CS rate of 32 % was chosen based on the nulliparous rate at Abbotsford Regional Hospital 2015–2016 [13]. The final model from the original study had seven independent predictors and three that had been predictive of CS only in univariate analysis. To test ten candidate variables in the model the sample size needed would be 313 [9]. An extra 10 % was added to compensate for the possibility of erroneously enrolled women for a final sample size of 344.

Statistical analysis

Assessment of the Janssen predictive model in the Abbotsford data

To assess the performance of *the Janssen predictive model,* risk scores were calculated for all Abbotsford women using the parameters from the Janssen model. A Receiver Operating Characteristic (ROC) curve was computed and the Area Under the Curve (AUC) i.e. C-statistic calculated. The C-statistic assesses model discrimination, the probability that a randomly selected woman with a CB had a higher risk score than a randomly selected woman who did not have CB, was calculated [14]. The following categories were considered when interpreting the ROC: non informative (C-statistic=0.5), poor accuracy (0.5 <C-statistic≤0.7), moderate accuracy (0.7<C-statistic≤0.9) and high accuracy (0.9 <C-statistic<1), perfect test (C-statistic=1) [15].

Development of a predictive model in the Abbotsford data

Using the Abbotsford data, characteristics for women with CB vs vaginal birth were compared using Mann-Whitney test for continuous variables and Chi-square test for categorical variables. Sociodemographic candidate variables that were distributed differently according to vaginal vs CB were evaluated univariately in logistic regression. The variable that was most significant in univariate analysis was retained in the model. Subsequently the remaining sociodemographic variables were tested individually with this variable. This was repeated in an iterative process. Sociodemographic variables independently significant at $p < 0.10$ were retained in the model as a block and then pregnancy–related and early labour-related indicators available at hospital admission were tested in a similar iterative process. The change in Chi-square for goodness-of-fit for the model was used to make decisions about retaining variables if the candidate variables had similar p-values. A logistic regression algorithm for CB was developed in the form of exp(w)/(1+exp(w) using retained variables. Predicted probabilities for CB for each patient were then calculated, a ROC curve computed and the C-statistic calculated.

Comparison of models' performance

The C-statistic of *the new predictive model* was compared with that of *the Janssen predictive model*. Variables that were significantly associated with CB only in univariate logistic regression in the original study by Janssen et al. [9] were tested to determine if they could incrementally improve the best performing model. A backward stepwise selection approach was used. Similarly, all variables significantly associated with CB in univariate analysis in the Abbotsford data were tested to evaluate if they could improve the model-fit. The − 2 Log likelihood ratio statistic was used for comparison; a significantly lower value of the − 2 log likelihood ratio would mean that the model with added variables was more accurately predicting CS than the baseline model [16]. The criterion for retention in this model was $p < .05$.

Evaluating the best performing model

Using the ROC curve of the best performing model, the value of the risk score that maximized sensitivity and specificity was determined and used to evaluate the accuracy of the predictive model. Sensitivity, specificity, classification accuracy, to which extent the persons with CB are identified as likely to have these outcomes, and positive and negative predictive values were calculated. An ROC value of 0.70–80 is considered to be an acceptable value [17].

The best performing model's calibration, how well the risk scores calculated reflect the actual percentage of women with the outcome, was assessed by comparing the predicted probability of CB with the observed outcomes of CB for each decile of the risk score. A calibration curve was then created and its slope and intercept (calibration-in-the-large) were assessed [18]. In a subgroup analysis aiming to determine if the model accuracy was modified by type of caregiver (midwife, family physician or obstetrician) the model-fit of these three groups was compared.

CB Prediction in First Stage of Labour

In a secondary analysis, with the aim of creating a predictive model for women in the active phase of labour after admission to the hospital, variables relevant for progress in first stage were evaluated together with the best performing model. (Fig. 1) This was tested using logistic regression and − 2 log-likelihood ratios. A p-value< 0.05 was used as a limit for inclusion in the model. Subsequently a ROC for this first-stage-model was created. IBM SPSS Statistics version 25.0 (IBM Corporation, Armonk, NY) was used for statistical analysis.

Results

Characteristics of study population

Of the 348 women who met inclusion criteria, 106 (30.5 %) had a CB and 242 (69.5 %) delivered vaginally. Women with CB were older compared to women with vaginal birth. Pre-pregnancy weight, BMI or maternal height did not differ in-between the groups, nor did alcohol habits, smoking habits or illicit drug use, see Table 1. Women with CB more often gave birth after week 40 + 0, their primary caregiver was more often an obstetrician, they were more often admitted to the birthing ward with a lesser cervical dilatation and more often received oxytocin augmentation of labor compared to women with vaginal birth, see Tables 2 and 3.

Predictive modelling in the Abbotsford data

Applying the *Janssen predictive model* to the Abbotsford data, the risk score was calculated for each patient (with complete information for predictor variables, n = 269) in the dataset using the variables: age, gestational age, height, onset> 24 h before admission, regularity of contractions, cervical dilatation and fetal station on admission. The risk score was calculated using the algorithm: exp(w)/[1 +exp(W)] and w= [− 20.204 + (0.109 × maternal age (years))-(0.017 × maternal height (cm)) + (0.078 x gestational age (days))-(0.634 x regular contractions =1, otherwise 0) + (0.901 x mother's perception of pre-hospital labour >24 h =1, otherwise 0) - (0.546 x cervical dilation (cm)) - (0.064 x station of fetal vertex). To determine how well the continuous risk score could predict CS a ROC was created with a resulting C-statistic of 0.77, see Fig. 3.

In univariate logistic regression for the model generated by the Abbotsford data, higher maternal age (OR: 1.11, CI: 1.05–1.18), gestational age at admission (OR:1.05, CI: 1.01–1.09), higher symphysis fundal height (OR: 1.18, CI: 1.02–1.36), lesser cervical dilatation (OR: 0.63, CI: 0.53–0.74), higher fetal station (OR: 0.63, CI: 0.47–0.82) and lesser cervical effacement (OR: 2.28, CI: 1.40–3.99) at admission were all associated with an increased risk of CS. Prior visits to hospital before birthing admission was also predictive of CS (OR: 1.62, CI: 1.02–2.57). Independent predictors of CS were: maternal age, cervical dilatation, gestational age, and onset of contractions more than 24 h before admission, see Table 4. The ROC for the *new predictive model* with these four variables had a C-statistic of 0.75 (including only participants with complete information for predictor variables, n = 331), see Fig. 2.

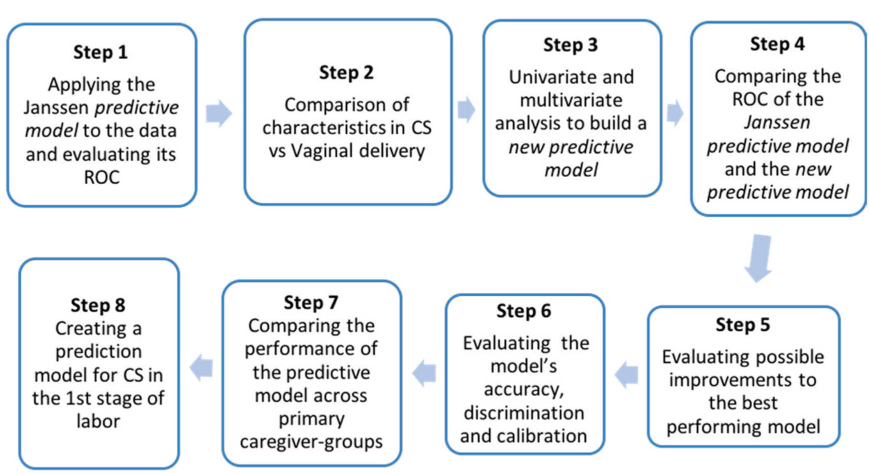

Fig. 1. Flowchart of statistical analysis.

Table 1
Sociodemographic and lifestyle characteristics of the study sample.

Characteristics	Vaginal Birth (n = 242)	Caesarean Birth (n = 106)	p–value
Age (years)	27.0 ± 4.2	28.9 ± 4.1	< **0.005**
Age groups:			
- **≤24**	69 (28.5)	15 (14.2)	**0.001**
- **25–29**	104 (43.0)	45 (42.5)	
- **30–34**	63 (26.0)	36 (34.0)	
- **35–39**	6 (2.5)	10 (9.4)	
Height (cm)	166.4 ± 6.7	165.8 ± 6.4	0.37
Missing	14	5	
Ethnicity			
- **Caucasian**	165 (70.5)	66 (64.7)	0.54
- **East Asian**	9 (3.8)	4 (3.9)	
- **South Asian**	50 (21.4)	29 (28.4)	
- **Other**	10 (4.3)	3 (2.9)	
- **Missing**	8	4	
Marital status			
- **Have partner**	233 (96.7)	102 (97.1)	0.82
- **Missing**	1	1	
Educational level			
- **High school or less**	68 (39.3)	16 (26.2)	0.18
- **Some postsecondary/ college/**	53 (30.6)	22 (36.1)	
- **trade school**			
- **Some university/ university degree**	52 (30.1)	23 (37.7)	
- **Missing**	69	45	
Tobacco use			
- **Never**	194 (83.3)	86 (84.3)	0.89
- **Former**	27 (11.6)	12 (11.8)	
- **Current**	12 (5.2)	4 (3.9)	
- **Missing**	9	4	
Illicit drug use			
- **Never**	213 (91.4)	95 (93.1)	0,67
- **Former**	11 (4.7)	5 (4.9)	
- **Current**	9 (3.9)	2 (2.0)	
- **Missing**	9	4	
Alcohol use			
- **Never**	180 (77.6)	80 (78.4)	0.51
- **Former**	49 (21.1)	22 (21.6)	
- **Current**	3 (1.3)	0	
- **Missing**	10	4	
Pre-pregnancy BMI	23.5 ± 3.9	24.0 ± 4.0	0.24
BMI groups			
- **Underweight (<18.5)**	8 (3.9)	5 (5.6)	0.83
- **Normal (18.5–24.99)**	137 (66.8)	57 (64.0)	
- **Overweight**[25–30]	48 (23.4)	20 (22.5)	
- **Obese (>30)**	12 (5.9)	7 (7.9)	
- **Missing**	37	17	
Pre-pregnancy weight (kg)	65.0 ± 11.3	66.2 ± 12.4	0.54
Missing	33	16	

Results presented as mean ± SD or n (%). Mann-Whitney test was used for continuous and Chi-Square for categorical variables. BMI = Body Mass Index, SD = Standard Deviation.

Table 2
Obstetrical Characteristics of study sample at admission to hospital.

Characteristics	Vaginal Birth (n = 242)	Caesarean Birth (n = 106)	p–value
Total gestational age (days)	278.2 ± 6.5	280.2 ± 6.2	0.009
- **Before week 40 + 0**	153 (63.5)	49 (46.2)	0.003
- **After week 40 + 0**	88 (36.5)	57 (53.8)	
Symphysis fundal height (cm)	36.7 ± 2.0	37.4 ± 2.4	0.077
Missing	95	41	
Doula present			
- **Yes**	16 (6.6)	7 (6.6)	0.998
Primary caregiver			
- **Midwife**	63 (26.0)	24 (22.6)	0.030
- **Family practice physician**	127 (52.5)	45 (42.5)	
- **Obstetrician**	52 (21.5)	37 (34.9)	
Prior visits to triage before admission			
- **Yes**	86 (35.5)	50 (47.2)	0.041
Maternal perception of onset of contraction s > 24 h before admission			
- **Yes**	40 (16.9)	24 (23.8)	0.14
- **Missing**	6	5	
Regular contractions			
- **Yes**	200 (84.4)	83 (80.6)	0.39
- **Missing**	5	3	
Intensity of contractions			
- **Mild**	30 (13.1)	16 (15.8)	0.68
- **Moderate**	153 (66.8)	68 (67.3)	
- **Strong**	46 (20.1)	17 (16.8)	
- **Missing**	13	5	
Station of fetal head			
- **≥0**	160 (78.0)	84 (90.3)	0.011
- **< 0**	45 (22.0)	9 (9.7)	
- **Missing**	37	13	
Cervical dilatation			
- **> 5 cm**	68 (28.3)	9 (8.7)	< 0.005
- **3–5 cm**	153 (63.7)	67 (65.0)	
- **0–2 cm**	19 (7.9)	27 (26.2)	
- **Missing**	2	3	
Cervical length			
- **< 0.5 cm (>75 % effaced)**	136 (61.3)	51 (52.6)	0.041
- **0.5–0.99 cm (50–75 % effaced)**	53 (23.9)	20 (20.6)	
- **1–2 cm (0–50 % effaced)**	33 (14.9)	26 (26.8)	
- **Missing**	20	9	
Membrane status			
- **Ruptured**	89 (36.8)	35 (33.0)	0.50

Results presented as mean ± SD or n (%). Mann-Whitney test was used for nominal and Chi-Square for categorical variables. SD = Standard Deviation.

Extension of the Janssen predictive model

Since the *Janssen predictive model* performed better than the *new predictive model* in the Abbotsford data (C-statistic of the Janssen model: 0.77 compared to the new model: 0.75), we continued evaluating the *Janssen predictive model*. Inclusion of variables significant in univariate but not multivariate logistic regression (pre-pregnancy BMI, SF height and intensity of contractions from the original study and cervical effacement and prior visits to triage in the new model) did not improve the predictive ability of the model.

In further evaluation of the *Janssen model's* performance using the Abbotsford data, the mean predicted risk score for CB was calculated to be 0.30 ± 0.20. From the ROC curve the cutoff was optimized at the predicted probability of 0.32. At this cutoff, the sensitivity was 69 % [58–79], specificity of 69 % [62–75], classification accuracy 69 % [63–74], positive predictive value 49 % [42–55] and negative predictive value [79–88], see Table 5. The median predicted risk score of CB was higher among women with CB than among women with vaginal birth (0.43 vs 0.20, $p < 0.005$). Having a risk score above the dichotomized score was significantly associated with CB; women with a score > 0.32 were 5 times more likely (OR: 4.9, CI: 2.8–8.6) to have a CS compared with women with a score < 0.32.

The model's calibration is illustrated in Table 6. In the group with the highest predicted risk which represented 1.5 % of the women, 75 % had CB and only 25 % had vaginal birth. see Table 6. In the group with the lowest predicted risk, which represented 17 % of the women, none had CB. These results can also be assessed graphically, see Fig. 4. The calibration curve showed good calibration overall with an intercept of 0.023 (ideally 0) and approximate linearity of the slope of 0.93 (ideally 1), see Fig. 4 [18].

In summary, women who were older, shorter, having experienced contractions for more than 24 h before admission, with irregular contractions, greater gestational age, and lower fetal station and cervical dilation at presentation to hospital were more likely to have a caesarean section. These parameters can be quickly assessed as part of a routine admission examination. Our algorithm allows for measurements of these parameters to be combined into a single risk score that could be used to inform an individual care plan.

Table 3
Labour characteristics of study population.

Characteristics	Vaginal Birth (n = 242)	Caesarean Birth (n = 106)	p–value
Epidural			
- **Yes**	92 (38.0)	75 (70.8)	**< 0.005**
Narcotics			
- **Yes**	141 (58.3)	65 (61.3)	0.59
Augmentation of labour			
- **Yes**	137 (56.6)	74 (69.8)	**0.020**
Type of augmentation			
- **Assisted rupture of membranes**	86 (62.3)	23 (31.1)	**< 0.005**
- **Oxytocin**	24 (17.4)	27 (36.5)	
- **Assisted rupture of membranes + Oxytocin**	28 (20.3)	23 (31.1)	
Electronic fetal monitoring			
- **Continuous**	133 (55.2)	87 (82.1)	**< 0.005**
- **Intermittent**	93 (38.6)	17 (16.0)	
- **Assessment room only/none**	15 (6.2)	2 (1.9)	
- **Missing**			
Length of first stage (minutes)	591 ± 307	365 ± 226	**< 0.005**
Length of first stage> 20 h			
- **Yes**	61 (25.2)	61 (58.7)	< 0.005
Length of second stage (minutes)	93.3 ± 123.6	85.3 ± 63.0	< 0.005
Length of second stage> 3 h			
- **Yes**	21 (8.7)	34 (32.4)	< 0.005
- **CS in first stage**	-	61 (58.1)	

Results presented as mean ± SD or n (%). Mann-Whitney test was used for continuous and Chi-Square for categorical variables. ARM = Assisted Rupture of Membranes, SD = Standard Deviation.

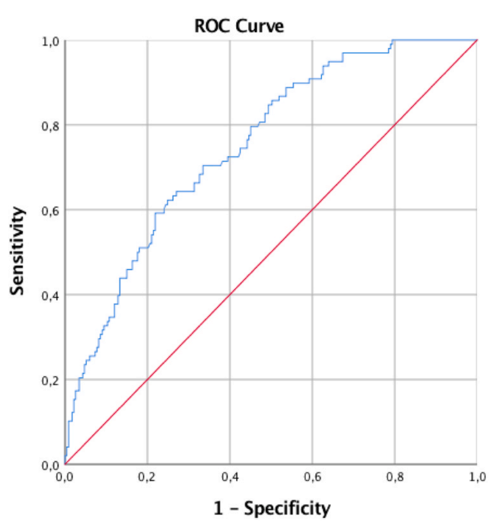

Fig. 2. ROC for the new predictive model in the Abbotsford data set. Receiver Operating Characteristics (ROC) curve for the new predictive model of Caesarean Section using the variables: maternal age (years), gestational age (days), onset of labour> 24 h at admission and cervical dilation (cm).

Subgroup analysis by primary care provider type

There was a statistically significant (p = 0.03) association between care provider type and the mode of birth. Midwife clients had a CB rate of 26.7 %, family physicians 26.2 % and obstetricians 41.6 %. When adjusted for maternal age, educational level, ethnicity and BMI the OR for CB for obstetricians vs. family physicians or midwives was 2.6 (CI: 1.08–6.06). When assessing the performance of the *Janssen predictive model* in the caregiver subgroups the C-statistic, the sensitivity, positive predictive value, negative predictive value and classification accuracy were highest in the group of women with an obstetrician as primary caregiver, see Table 7.

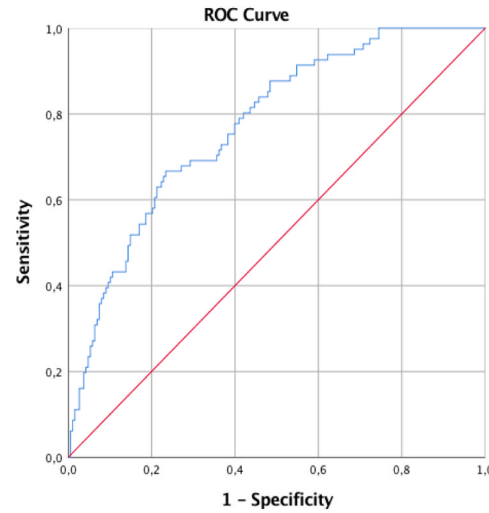

Fig. 3. ROC for the Janssen predictive model in the Abbotsford data set. Receiver Operating Characteristics (ROC) curve for the Janssen predictive model of Caesarean Section using the variables: maternal age (years), maternal height (cm), gestational age (days), regularity of contractions, onset of labour > 24 h at admission, cervical dilation (cm) and fetal station.

Table 4
Independent predictors of CS in multivariate logistic regression.

Predictor	Adjusted OR (95 % CI)
Age (years)	1.11 (1.04–1.18)
Gestational age (days)	1.06 (1.02–1.11)
Onset of contractions> 24 h before admission	1.95 (1.034–3.69)
Cervical dilatation on admission (cm)	0.61 (0.51–0.73)

CI = Confidence Interval. ORs adjusted for all other variables listed.
For continuous variables the OR represents the change per unit of change in the continuous variable.

Table 5
Performance of the predictive model.

Sensitivity	Specificity	Classification accuracy	Positive predictive value	Negative predictive value
69 % [58–79]	69 % [62–75]	69 % [63–74]	49 % [42–55]	84 % [79–88]

Calculated using the risk score cutoff of 0.32. Confidence Interval 95 % in parenthesis, LR = likelihood ratio.

Table 6
Calibration of the predictive model.

Deciles of risk score	Mean predicted risk of CS ± SD	Observed Frequency of CS	
		n	%
0–0.1	0.05 ± 0.03	0/46	
0.1–0.2	0.15 ± 0.03	10/59	0.17
0.2–0.3	0.24 ± 0.03	15/41	0.37
0.3–0.4	0.34 ± 0.02	11/43	0.26
0.4–0.5	0.45 ± 0.03	13/30	0.43
0.5–0.6	0.54 ± 0.03	12/20	0.60
0.6–0.7	0.65 ± 0.03	11/17	0.65
0.7–0.8	0.72 ± 0.03	6/9	0.67
0.8–0.9	0.82 ± 0.02	3/4	0.75

CS = Caesarean section, SD = Standard deviation.

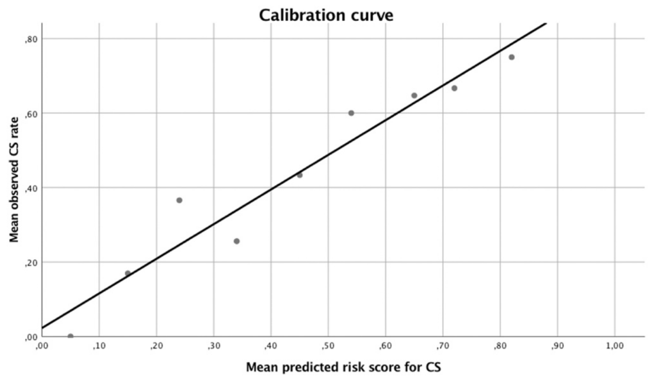

Fig. 4. Calibration curve for the predictive model. Mean predicted risk score of CS/decile of risk on X-axis, Mean CS rate/decile on Y-axis. CS: Caesarean Section.

Table 7
Performance of the predictive model in caregiver-groups.

	Obstetrician n = 89	Family physician n = 172	Midwife n = 87
C-statistic	0.83	0.78	0.76
Sensitivity	88 %	70 %	55 %
Specificity	65 %	75 %	71 %
Positive predictive value	64 %	51 %	42 %
Negative predictive value	88 %	88 %	80
Classification accuracy	74 %	74 %	67 %

Sensitivity/specificity, positive/negative predictive value and classification accuracy were calculated using the risk score cutoff of 0.32.
C-statistic = Area Under the ROC Curve, ROC = Receiver Operating Characteristic.

Testing the model with first stage parameters

In a secondary analysis, interventions in the first stage of labour after admission were tested as predictors. When adding epidural and the use of continuous electronic fetal monitoring (compared to intermittent auscultation) to the *Janssen predictive model* the predictive ability was improved (−2 log likelihood ratio decreased from 272 to 254, $p < 0.005$) and the ROC-curve (see Fig. 5) now had a C-statistic of 0.81. Neither augmentation of labour nor use of narcotics significantly contributed to the model.

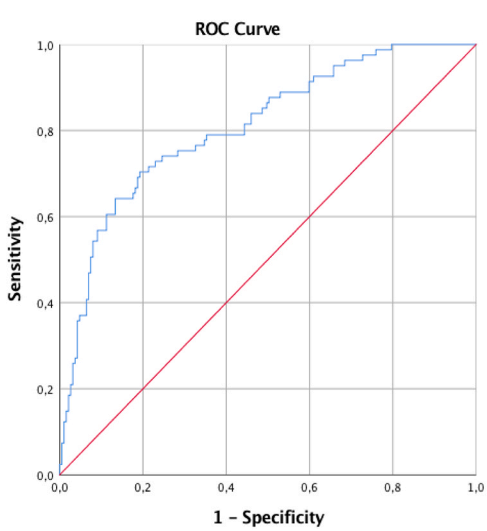

Fig. 5. ROC for the predictive model in first stage of labour. Receiver Operating Characteristics (ROC) curve curve for the predictive model of Caesarean Section in the 1st stage using the variables: maternal age (years), maternal height (cm), gestational age (days), regularity of contractions, onset of labour> 24 h at admission, cervical dilation (cm), fetal station, epidural and electronic fetal monitoring.

Discussion

In this study we validated the predictive model developed by Janssen et al. [9] in a new obstetric care setting with C-statistic of 77 % (compared to 71 % in the original study) indicating an acceptable discriminative ability in predicting CB. Women with risk scores above the cutoff had a five-fold increase in probability of CB. This model can be applied for prediction of CB in nulliparous women using easily accessible data at hospital admission using maternal demographics, prenatal records and examination at admission.

In a 2017 study, Burke et al. [19] developed a predictive model for emergency caesarean section in nulliparous women at term based on data collected before onset of labour. They included maternal age, height, BMI, fetal abdominal circumference and fetal head circumference (measured by ultrasound in week 39) and achieved a C-statistic of 69 %. In our study the C-statistic was 77 % without the requirement to use ultrasound. In April 2019 an ultrasound based “Intrapartum App” for prediction of mode of delivery was published [20]. It is based on a study from 2014 in which the authors developed a prediction model for the likelihood of vaginal birth using maternal characteristics, intrapartum transabdominal and transperineal ultrasound to assess fetal head position and fetal head station [21]. The model showed good discrimination with a C-statistic of 85 %. This approach would however, require access to ultrasound technicians and machines, which are not available in many rural settings. Even in urban settings, ultrasound resources can be limited in terms of staff, and the time required for examination might be prohibitive for most women at hospital admission or triage.

High maternal age and short stature are known to increase the risk of CB and our results are consistent with the findings in the literature [22]. Both multiple visits to the triage before admission and maternal perception of contractions lasting > 24 h before admission are symptomatic of a prolonged latent phase which is known to increase the risk of intrapartum interventions and CB [23]. Having visited triage before admission was univariately associated with CS but when adjusted for onset > 24 h before admission the association was no longer significant.

Higher fetal station and lesser cervical effacement were both significantly associated with CS in univariate analysis but were dropped in the multivariate analysis when adjusted for cervical dilatation. Admission in early labour with a closed cervix increases the risk of CB. Biological reasons for this remain relatively unexplored.

Admission to the birthing ward in latent phase, defined by the World Health Organization as cervical dilatation up to 5 cm, is known to influence rates of intervention and CB [24,25]. In our CB group, 91.2 % of women were admitted with a dilatation of 5 cm or less. Irregular contractions, included in our final model, might be a proxy for less cervical dilation, or latent phase labour. Avoidance of hospital admission prior to the active phase of labour may safely decrease CB rates. It must be acknowledged, however that avoidance of admission to hospital does not negate the need for skilled labour support. A Cochrane review claims that early labour support compared to direct admission could decrease the use of epidural, augmentation of labour and increase maternal satisfaction with care [26]. Knowledge of a women’s elevated risk for CB a could prompt a caregiver to offer early labour support to these women.

In the subgroup analysis of primary caregivers, women receiving care from an obstetrician compared to a family physician/midwife had an increased risk of CB. In a country with a high rate of obstetrician-led deliveries it might be time to question if an obstetrical approach to primary care for low risk women is appropriate.

When adding the predictors epidural and continuous electronic fetal monitoring to the model a first stage-model for CB was created with a C-statistic of 81 %. In our study 52 % of women cared for by obstetricians, 55 % of women cared for by family physicians and only 30 % of women with a midwife as caregiver had an epidural ($p < 0.05$). Continuous electronic fetal monitoring was used in 69 % of obstetrician-led deliveries, 67 % of family physician-led deliveries and 51 % of midwife-led deliveries ($p = 0.038$). This suggests that approaches to pain management and monitoring differs among caregiver groups and this influences the risk of CB.

A limitation of our study was that women were not asked about their preferred mode of birth. Anxiety, lack of coping strategies or fear of vaginal birth may play a part in predicting CB. It might be that women choosing an obstetrician as their provider of care are more prone to accept CB rather than enduring labour, which could explain the higher CB rate in this caregiver-group. Our study was also limited by its retrospective nature, small sample size and missing values for important variables (including BMI, pre-pregnancy weight, symphysis fundal height and fetal station).

A potential drawback to using a risk score could be reluctance to continue to plan a vaginal birth on the part of the patient. There is also a risk that the knowledge of a risk score may alter the clinician's judgement in favour of caesarean section. However the opposite could apply for women with a low risk score but in prolonged labour. Future studies could further evaluate models for different caregiver-groups. Lastly, our tool could be used to study interventions initiated as a result of knowledge of risk score, for example, more effective pain management, change of position, increased mobility, more fluids to avoid dehydration and earlier augmentation of labour.

Our findings are generalizable to healthy women experiencing uncomplicated singleton pregnancies presenting at term in spontaneous labour. All of the assessments that comprise the risk assessment could also be conducted in home birth or birth centre settings.

Conclusion

This study validates a predictive model for caesarean birth in low risk nulliparous pregnancies using parameters routinely measured at hospital admission. Knowing the results of the risk scoring may support women with low risk scores (high probability of vaginal birth) who, along with their caregivers, to anticipate vaginal birth despite discouragement associated with slow progress or other factors. Conversely, the results may encourage close monitoring and intensive support for women at higher risk, of cesarean birth with the ultimate goal of reducing CB rates and associated morbidity. We hope that our CB prediction score will function as an additional tool with which women and their caregivers can practice shared decision-making, taking into account women's individual needs and preferences.

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None declared.

Ethical statement

The study received a Certificate of Ethical Approval from the Fraser Health Authority Research Ethics Board, Number 2016063, August 25, 2016. Individual consent was not obtained as the data received from Perinatal Services BC is anonymized.

CRediT authorship contribution statement

Both authors contributed to the conceptualization and design of the study. P. Janssen supervised data collection. L. Ladfors conducted the statistical analysis and wrote the first draft of the paper. P. Janssen completed the final version of the manuscript.

Conflict of interest

None Declared.

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