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Ultrasound assessment of cervical status compared to the Bishop score – predicting the success of labor induction using a machine learning-based model

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Abstract. – OBJECTIVE: The main aim of this study was to develop a machine-learning-based model for predicting the success of labor induction (IOL). To that end, the clinical and ultrasound parameters that affect the successfulness of labor induction were assessed. Then, a new ultrasound scoring system (USS) was developed and assessed.

PATIENTS AND METHODS: This prospective observational study included 192 term women who underwent induction of labor. First, a wide range of clinical and ultrasound pre-induction parameters were recorded. The induction was initiated by endocervical administration of dinoprostone gel (for Bishop score ≤5) or intravenous oxytocin (for Bishop score ≥6). After evaluating ultrasound parameters, we created an ultrasound scoring system and compared it with the Bishop score and clinical parameters. Finally, a comprehensive model using machine learning algorithms for predicting the success of the induction of labor was developed.

RESULTS: In terms of clinical parameters, this study found that IOL correlates with parity, body mass index (BMI) (both at $p<0.05$), and the Bishop score ($p<0.001$). All ultrasound parameters were statistically significant ($p<0.05$) apart from the posterior cervical angle. However, compared to the Bishop score, the new USS showed a slightly lower sensitivity (0.55 compared to 0.64) but much higher specificity (0.75 compared to 0.44) at a cut-off of 1.66. The proposed model, which can predict 83% of the events correctly, encompasses the Bishop score, USS, and clinical parameters.

CONCLUSIONS: The findings imply that the model developed in this study, which takes into account clinical parameters (parity, BMI), the ultrasound parameters and the Bishop score and uses machine learning algorithms, yields better results than models using other parameters.

Key Words:
Labor, Induced, Risk factors, Cesarean section, Ultrasonography, Models, Machine learning.

Introduction

There is a growing trend toward induction of labor (IOL) and approximately 20% of labors are induced[1,2]. However, the induction of labor is not always successful and carries risks. It increases the risks of instrumental termination of labor (15%) and emergency cesarian section (20%)[3-5]. The risk of ending labor by emergency cesarean section is 2-3 times higher after labor induction, especially among primiparous women[6]. It can also be associated with uterine hyperstimulation, fetal hypoxia, postpartum hemorrhage, uterine rupture, and, in extremely rare cases, maternal and fetal death[7]. Additionally, studies[8,9] in the field of neonatology have shown that IOL increases the frequency of lower Apgar scores, impossible (delayed) breastfeeding, admission of newborns to intensive care units, and stillbirths. Therefore, it is necessary to use a method that could predict the success of IOL with some reliability. Induction of labor with an unfavorable cervix is often difficult[10]. In the absence of a new system, the Bishop score remains the most commonly used method for the maturity of the cervix evaluation. However, its sensitivity in predicting birth outcomes is 23-64%[11,12]. So far, research has been primarily aimed at simplifying the Bishop score[11,13], but more recent studies[14,15] have tried to objectify some sonographic

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parameters, such as cervical length or funneling. In addition, several papers emphasize the advantages of transvaginal ultrasound examination over bimanual examination: more precise cervix measurement, easier reproducibility and reduced interobserver variations. When predicting the success of induced labor, the integrity, complexity, and dynamics of the labor process and the nonlinear synergy among various risk factors need to be considered. Therefore, to deal with all the multivariate nonlinear data, machine learning algorithms were successfully used[16].

The present study aims to develop a new model by assessing the relationship between patients' clinical and ultrasound parameters and the outcome of labor induction. We have selected the following ultrasound parameters: cervical length, size of the posterior angle of the cervix or its position, the length and width of funneling, distance of the fetal head from the external cervical os, and position of the fetal head. Previous studies[17-22] showed that these correlate with successful induction. Therefore, these parameters were incorporated into the new ultrasound scoring system (USS) and compared with the Bishop score and clinical parameters.

Patients and Methods

Design of the Study and Participants

This prospective observational study, from a single center, included 192 women. These patients were admitted for IOL at the Department of Obstetrics and Gynecology, the University Clinical Centre of Vojvodina (Novi Sad, Serbia), during the years 2020-2021. The eligibility criteria for participation in the study were: singleton pregnancies with a live fetus, vertex presentation, between 37 and 42 weeks of gestation, and medical indication (fetal or maternal cause) for labor induction. Other inclusion criteria were pregnant women aged 18-40, pregnant women with regular menstrual cycles and a known date of the first day of the last menstruation period, or the estimated date of delivery (EDD) between 11^{+0} - 13^{+6} weeks of gestation (based on an ultrasound examination). Indications for labor induction were post-term pregnancy, a hypertensive disorder in pregnancy, oligohydramnios, favorable obstetric findings, PROM, diabetes mellitus, and intrauterine growth restriction. The women with hypertensive diseases were split into four groups: chronic hypertension, gestational hypertension, preeclampsia, or superimposed preeclampsia. In the diagnostics of gestational hypertension and preeclampsia, we relied on ACOG guidelines[23,24]. The exclusion criteria were: maternal age <18 or >40, unknown date of the first day of the last menstruation period and unknown EDD, previous uterine surgery (cesarean section, myomectomy), congenital anomalies of the fetus, fetal death, twin gestations, earlier interventions on the cervix (conization, LLETZ, cerclage), prenatal diagnosis of fetal macrosomia, regular uterine contractions, COVID-19 infection or any contraindication for vaginal delivery or a patient's refusal to participate in the study.

Predictors and Data Preprocessing

The following clinical data were considered: patients' age, parity, body mass index (BMI), gestational age, estimated fetal weight, and obstetrics indication for the IOL. All the pregnant women underwent a palpable bimanual examination, and cervical maturity was assessed using the Bishop score. Before the onset of induced labor, transvaginal and abdominal ultrasound was performed. Ultrasound examination was performed using a Samsung Medison UGEO VS80A equipped with a transvaginal probe (2-10 MHz) and curved linear transducer (3-7.5 MHz). The Fetal Medicine Foundation protocol[25] was followed in the procedure. The posterior cervical angle was measured as the angle between an imaginary line traversing the cervical canal and another tangential to the posterior uterine wall at its junction with the internal os[17]. The distance between the presenting part (head) and the external os was measured. Transabdominal ultrasound examination assessed the fetus's body weight and head position. The landmarks used to determine the fetal head position were the fetal orbits for the occiput-posterior (OP) position, the midline cerebral echo for occiput-transverse positions (OT), and the cerebellum or the occiput for occiput-anterior (OA) position[17].

Induced Labor Scheme

If the Bishop score was ≤5, the induction was initiated by endocervical administration of dinoprostone gel (0.5 mg/3 g; 2.5 ml gel). If the Bishop score was ≥6, the labor was induced with intravenous oxytocin, 5 IU in 500 ml of isotonic solution, at a rate of eight drops per minute.

Outcomes

Successful induction of labor is a vaginal delivery within 24 hours from the beginning of the labor induction. In contrast, unsuccessful IOL ends with surgery (cesarean section), i.e., the termination of induction of labor due to non-progression

of labor. The unsuccessful labor induction group included cases of induction failure (the absence of response to the induction protocol) and functional dystocia, suggesting that labor induction was ineffective. Failed labor induction was defined as failure to progress in the setting of ruptured membranes, oxytocin infusion for ≥12 h, and cervical dilation <6 cm[26]. Labor dystocia in the first stage of labor was defined as failure to progress at cervical dilation ≥6 cm with ruptured membranes and adequate contractions for a minimum of 4 hours. Labor dystocia in the second stage of labor was defined as failure to deliver at cervical dilatation of 10 cm after ≥1 h of active pushing or failed operative vaginal delivery[26]. We did not evaluate the cases involving changes in fetal well-being. The women who had cesarean delivery for fetal distress were excluded because this can be caused by other factors (placental insufficiency or abruption).

Development of Machine Learning-Based Model

The machine learning-based prediction model developed in this study uses clinical and ultrasound parameters to assess the success of IOL. Machine learning algorithms address problems where analysis of available data sets is used to predict the outcome of certain events. Since available data in this research are already labeled (the expected result value was known), the selection of algorithms was limited to supervised learning algorithms. Four algorithms were compared in the algorithm selection process: Random Forest classifier[27], AdaBoost classifier[28], Extra Trees classifier[29] and Logistic Regression classifier[30]. The precision, recall, and F1 score comparison shows that the AdaBoost algorithm is the best fit for this problem. AdaBoost is an iterative, ensemble learning algorithm that consists of decision tree sets. In each iteration, those trees are tested, and their weights are adjusted. Special attention is given to those samples where the classification was made incorrectly in the previous iteration. The final classification result is created using the base estimator, which considers the prediction of each individual tree and makes a decision based on the majority principle[31]. A Stratified K-Fold cross-validation technique was used to check the developed model internally and to prevent overfitting[32]. This technique extracts a part of the training set into a new validation set. The validation set is used to check how the developed model is progressing in the learning process and whether there is a need to change the model's hyperparameters. The advantage of this kind of internal validation method is that each class can be represented in the training and validation set according to its frequency in the initial data set. In this research, the internal validation was performed in 3 passes (K=3), i.e., the proposed model was internally tested in 3 iterations on 3 different validation sets.

Statistical Analysis

Statistical analysis was performed in Python and is presented in the tables. Descriptive analysis shows the mean values of clinical and ultrasound parameters by the success of labor induction (Table I) and parity (Table II). Pearson's Chi-squared test was applied to check the significance of the results. Statistically significant results were those with $p<0.05$. We created an ultrasound scoring system after evaluating clinical and ultrasound pre-induction parameters. The new USS was compared with other parameters using AdaBoost. Finally, the machine learning-based predicting model was created to analyze the success of the IOL.

Results

Baseline Characteristics

A total of 192 women fulfilled the inclusion criteria and were enrolled in the study. Twelve participants underwent a cesarean delivery for unpredictable indications (e.g., fetal distress) and were excluded from the study. So, a total of 180 pregnancies were included in the analysis (Figure 1). Most of the patients (149) had a vaginal delivery (Group 1), and only 31 gave birth by cesarean section (Group 2). These two groups were divided into primipara and multipara subgroups (Table II). Among the women who had successful induction of labor (Group 1), the majority (86, i.e., 57.72%) were with post-term pregnancy − the most common indication for the induction of labor. Other indications in group 1 were: hypertensive syndrome (16.11%), oligohydramnios (11.41%), favorable obstetric finding (6.04%), "other" (PROM, diabetes mellitus – 6.71%), and intrauterine growth restriction (1.34%). Only one patient had obstetric cholestasis (0.67%). As for the women who underwent cesarean section (Group 2), 15 (48.39%) had post-term pregnancy, and 10 (32.26%) had hypertensive syndrome. None of the women developed complications associated with labor induction, like uterine hyperstimulation and uterus rupture. There was no maternal or neonatal mortality.

Table I. The average value of clinical and ultrasound parameters by the success of induction of labor.

Characteristic	Successful induction (Mean±SD)	Caesarean section (Mean±SD)	*p*-value
Maternal age (years)	29.83±4.54	29.65±5.94	0.986
BMI (kg/m^2)	23.72±3.59	25.26±3.74	
20-25, n (%)	99 (66.4%)	15 (48.4%)	0.014
26-30, n (%)	31 (20.8%)	13 (41.9%)	
>30, n (%)	6 (4.0%)	2 (6.5%)	
Parity, n (%)	1.60±0.75	1.39±0.92	
Nulliparity, n (%)	80 (53.7%)	24 (77.4%)	0.024
Multiparity, n (%)	69 (46.3%)	7 (22.6%)	
Gestational age (weeks)	40.23±1.25	40.15±0.88	0.751
Estimated fetal weight (gram)	3,469.72±408.01	3,479.35±411.30	0.766
Burnett score	6.57±1.57	5.06±1.52	<0.001
Cervical length [mm]	25.52±7.09	29.06±6.77	0.018
Funneling length [mm]	7.06±5.36	5.16±6.75	0.040
Funneling width [mm]	3.83±2.67	2.39±2.88	0.009
Posterior cervical angle	113.89±15.51	110.90±21.01	
<120, n (%)	97 (65.1)	17 (54.8)	0.861
≥120, n (%)	52 (34.9)	14 (45.2)	
Fetal height [mm]	32.41±6.35	35.87±6.36	0.012
Position of the fetal head			
OP, n (%)	7 (4.7)	10 (32.3)	
OA, n (%)	33 (22.1)	6 (19.3)	0.046
OT, n (%)	109 (73.2)	15 (48.4)	

(BMI) body mass index, (OA) occiput anterior, (OT) occiput transverse, (OP) occiput posterior, (%) percentage of participants, (*p*) testing probability.

Table II. The average value of clinical and ultrasound parameters by the success of induction of labor.

Characteristic	Primipara (N=104)			Multipara (N=76)		
	Successful induction (N=80)	Caesarean section (N=24)	*p*-value	Successful induction (N=69)	Caesarean section (N=7)	*p*-value
Maternal age (years)	29.35±4.35	28.75±6.17	0.733	30.38±4.72	32.71±4.68	0.238
BMI (kg/m^2)	23.20±2.70	25.25±4.09		24.33±4.35	25.29±2.43	
20-25, n (%)	59 (73.75%)	11 (45.83%)	0.019	40 (57.97%)	4 (57.14%)	0.244
26-30, n (%)	15 (18.75%)	10 (41.67%)		16 (23.19%)	3 (42.86%)	
>30, n (%)	0 (0%)	2 (8.33%)		6 (8.70%)	0 (%)	
Gestational age (weeks)	40.32±0.96	40.37±0.73	0.909	40.12±1.52	39.39±0.98	0.093
Estimated fetal weight (gram)	3,456.75±385.56	3,542.92±362.51	0.315	3,484.75±434.96	3,261.43±546.58	0.239
Burnett score	6.11±1.65	5.00±1.64	0.003	7.10±1.30	5.29±1.25	0.002
Cervical length [mm]	26.61±6.69	28.71±6.97	0.199	24.25±7.37	30.29±6.92	0.041
Funneling length [mm]	5.90±5.17	5.12±7.39	0.250	8.41±5.31	5.29±5.12	0.176
Funneling width [mm]	3.33±2.78	2.33±3.10	0.140	4.42±2.42	2.57±2.44	0.034
Posterior cervical angle	114.45±16.29	110.12±22.58		113.23±14.64	113.57±17.77	
<120, n (%)	52 (65%)	14 (58.33%)	0.671	45 (65.22%)	3 (42.86%)	0.725
≥120, n (%)	28 (35%)	10 (41.67%)		24 (34.78%)	4 (57.14%)	
Fetal height [mm]	33.41±6.17	36.38±6.52	0.084	31.25±6.41	34.14±6.49	0.191
Position of the fetal head						
OP, n (%)	5 (6.25%)	8 (33.33%)		2 (2.90%)	2 (28.57%)	
OA, n (%)	16 (20%)	5 (20.83%)	0.044	17 (24.64%)	1 (14.29%)	0.642
OT, n (%)	59 (73.75%)	11 (45.83%)		50 (72.46%)	4 (57.14%)	

(BMI) body mass index, (OA) occiput anterior, (OT) occiput transverse, (OP) occiput posterior, (%) percentage of participants, (*p*) testing probability, (N) number of participants.

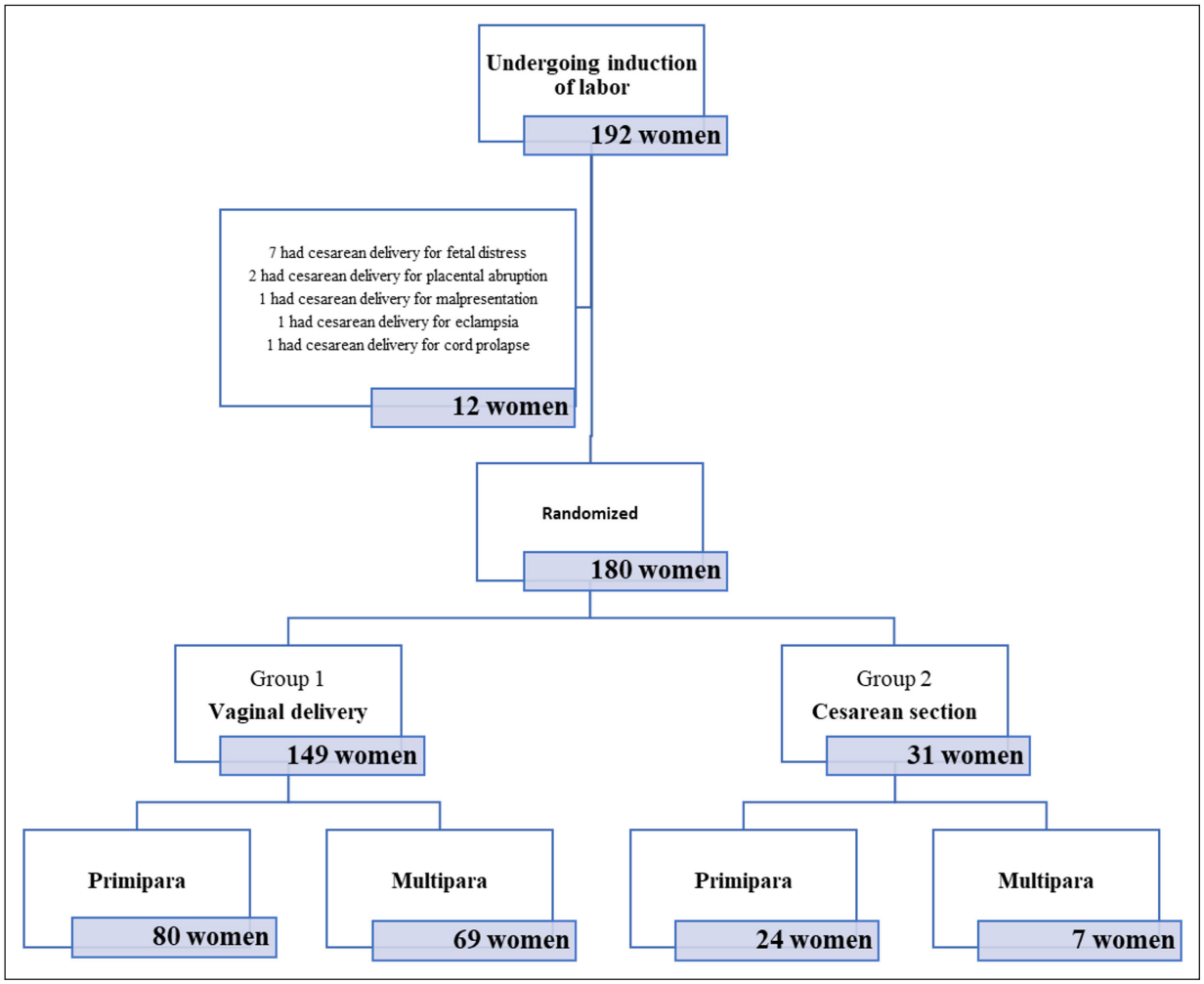

Figure 1. Selection process of studies included in the review.

Identification of Feature Importance

Table I shows the clinical and ultrasound characteristics of the study population. Regarding the clinical parameters, this study shows the significance of parity (p=0.024), BMI (p=0.014), and Bishop score (p<0.001). The most influential predictor was Bishop score, with a p<0.001. Gestational age and estimated fetal weight results have no statistical significance (p>0.05). As for the ultrasound parameters, statistically significant differences were found in cervical length, funneling width, fetal height, and position of the fetal occiput (p<0.05) (Table I). Therefore, these were included in the newly created USS (Table III).

Table III. Ultrasound scoring system (USS).

Score	0	1	2
Cervical length	>3 cm	2-3 cm	<2 cm
Funneling	Absent	≤0.5 cm	>0.5 cm
Fetal occiput	OP	OT	OA
Posterior cervical angle	<60	60-120	>120
Fetal height	>3 cm	2-3 cm	<2 cm

Score range (Minimum 0, maximum 10).

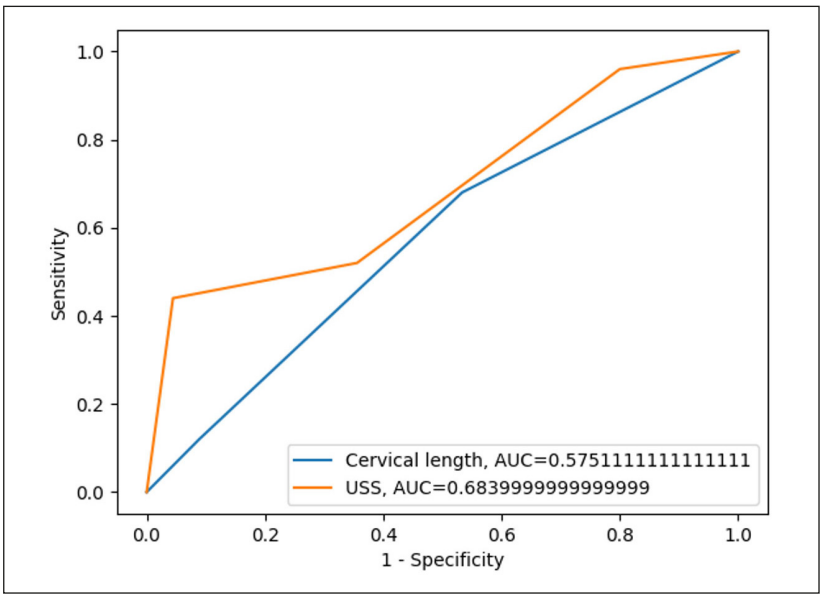

Figure 1. Selection process of studies included in the review.

These parameters are comparable to Bishop score parameters. Cervical length is comparable to effacement of the cervix, funneling to cervical dilatation and fetal height to the position of the fetal head. The position of the cervix is parallel to the posterior cervical angle. Next, the new USS was compared with other parameters. Figure 2 shows that the ultrasound scoring system [area under the curve (AUC) 0.68] seems to be a better predictor than the sonographic cervical length alone (AUC 0.57). Table IV compares diagnostic characteristics of the Bishop score and USS independently and in combination with statistically significant parameters (parity, BMI). The calculated AUC for the proposed model to predict cesarean delivery as an outcome of IOL was 0.84, which was higher than the AUC for both the individual Bishop (0.67) and USS (0.68) (Table IV).

Discussion

The success of IOL depends on the type of pregnancy, so we narrowed the sample to reduce risks. As stated in the Patients and Methods section, we did not include patients with COVID-19 infection, ZIKA virus, or other pathogens, as these are high-risk pregnancies. Women diagnosed with COVID-19 are at higher risk of preeclampsia/eclampsia, serious infections, need for intensive care, maternal mortality, preterm delivery including iatrogenic, perinatal morbidity, and mortality[33]. Additionally, in women who develop COVID-19 pneumonia, there is an increased risk of preeclampsia, preterm cesarean delivery, and due to fever and hypoxemia[33,34]. Zika virus infection[35] also results in high-risk pregnancies (e.g., microcephaly in children). Another reason

Table IV. Diagnostic characteristics of Burnett score and Ultrasound scoring system in predicting successful induction of labor.

Scoring	Cut-off	Sensitivity	Specificity	LR+	LR-	AUC
Burnett	1.74	0.64	0.44	1.15	0.81	0.67
USS	1.66	0.55	0.75	2.27	0.58	0.68
Burnett score with clinical parameters (BMI, parity)	1.99	0.48	0.90	4.80	0.58	0.77
USS with clinical parameters (BMI, parity)	1.99	0.65	0.86	4.67	0.41	0.83
Burnett + USS + clinical parameters (BMI, parity)	1.99	0.82	0.84	5.29	0.21	0.84

(BMI) body mass index, (USS) Ultrasound scoring system, (LR+) likelihood ratio positive, (LR−) likelihood ratio nega-tive, (AUC) area under the curve.

we excluded Zika virus pregnancies is that the clinic does not have established protocols for this infection. Our research included pregnant women with hypertensive syndrome and preeclampsia, which increase the risk of eclampsia and postpartum hemorrhage[24,36]. However, in these cases, we were aware of possible complications and had protocols ready to implement. Also, there were no complications after labor induction in the aforementioned diseases. Previous research[37-39] established that labor induction is more successful in multiparous than in nulliparous patients. Our study corroborates these results (Table I). While higher BMI is often associated with a longer duration of labor[39-41], some findings contradict these conclusions, claiming that BMI does not affect the outcome of labor induction[37,42,43]. Our study shows that BMI affects the outcome of labor induction (p=0.014). Traditionally, the Bishop score is the method of choice in assessing cervical maturity. Nevertheless, this score has its limitations. Several studies[44-46] that compared the predictive value of ultrasonographic indices to the Bishop score have generated contradictory results. Hence, the exploration of new parameters is needed to improve the assessment of the labor induction outcome[47]. To fill this gap, the present study assessed the usefulness of the ultrasonography of the cervix length and other ultrasound parameters in predicting a successful delivery after the induction of labor. Although some studies[48] performed a transperineal ultrasound examination for this purpose, we assessed the cervix maturity with a transvaginal ultrasound examination. Peregrine et al[2], Rane et al[49] and Pandis et al[50] found cervical assessments to be highly predictive and incorporated them in their IOL outcome predictive models. Like Rane et al[17] we also found that the length of the cervix, the posterior cervical angle, and the position of the fetal neck are more precise predictors of the IOL success than the Bishop score. Nevertheless, some studies[46,51] contradict these findings. The posterior occiput (OP) is associated with prolonged labor, third and fourth-degree perineal lacerations, bleeding, and consequent infections in the postpartum period[52]. A 2019 study[53] found that fetal occiput and spine position are dynamic in many women undergoing IOL. However, their assessment does not seem to correlate with the mode of delivery. We decided to determine the position of the fetus's occiput before starting labor induction because its influence was mentioned in a study by Popowski et al[54]. Given that our results on the link between the fetal occiput position and the mode of delivery were statistically significant (p=0.046), this parameter was included in the model. A recent systematic review[55] of 14 models derived or validated since 1966 provides a list of recommendations for improving the performance and utilization of the models. The scoring system proposed by Eggebø et al[56,57] includes digitally measured dilatation of the cervix but still needs to overcome the limitation of subjectivity. Bajpai et al[58] formulated an ultrasound scoring system with parameters matching the Bishop components and classified the position of the cervix as curved or straight. In contrast, we measured the posterior cervical angle according to the protocol instructions and used the USS for scoring. We can also find the Garg scoring system in the literature, which differs from ours because it was created using ultrasound measurements only on nulliparous women[18]. Kawakita et al[59] also developed a predictive model and reported independent predictors for successful vaginal delivery in nulliparous women who underwent IOL. An advantage of their retrospective study[59] is the number of participants (10,591). However, the predictors they used are mostly demographic, and data is based on clinical assessment of the cervix. The study by Tolcher et al[60] also included a relatively large number of female patients (785). They created a nomogram to predict cesarean delivery after IOL in nulliparous women. However, the introduced parameters represent a subjective assessment of cervical and maternal medical and demographic factors. Unlike the studies mentioned above, we performed the cervix assessment with ultrasound in order to reduce subjectivity and increase the accuracy of the results and, therefore, of the obtained model.

Limitations and Advantages of the Study

The present study has potential limitations that should be overcome in further research. First, the sample is small and limited to one population, which, together with the lack of external validation, implies an inherent risk of overfitting. Therefore, validating the proposed model through a more extensive multicenter study is required. Second, pregnant women with premature birth and vaginal birth after cesarean delivery (VBAC) were omitted. Third, an assessment of the IOL success with other methods not used at the Department of Obstetrics and Gynecology in Novi Sad (e.g., Foley catheter or misoprostol) is needed. Fourth, vaginal delivery depends

on the circumference of the fetal head and the mother's pelvis, which should be considered when assessing the outcome. Fifth, although some studies[61,62] provide information on cervical elastography and IOL, our research did not use this method. We would explore elastography as one of the parameters in further studies, intending to include it in USS. Therefore, although the model proposed in this study shows promising results, more research has to be done to confirm its efficiency and reliability.

On the other hand, the study has several advantages. First, all the pregnant women were consistently monitored until delivery. Second, the doctors who established indications for the induction of labor and managed the delivery did not know the ultrasound examination results before starting the induction of labor. Third, the patients who underwent cesarean section due to fetal distress and potential placental insufficiency were excluded from the sample. Therefore, this study provides an applicable, reliable, and objective model for predicting the success of labor induction. One planned step would be to transfer the proposed model to user-friendly platforms (computer software or mobile application).

Conclusions

The findings suggest that the machine learning-based model, using pre-induction sonographic parameters (Ultrasound Scoring System) together with clinical parameters and Bishop score, yields the best results in predicting the successfulness of IOL. Nevertheless, more research is needed for the complete validation of the model.

Ethics Approval

The study was conducted in accordance with relevant, local, national, and international guidelines with the permission of the Ethics Committee of the Faculty of Medicine, University of Novi Sad, Serbia Institutional Review Board Statement (Statement number 00−150). The study was conducted according to the guidelines of the Declaration of Helsinki.

Informed Consent

Written informed consent was obtained from the patients to publish this paper.

Conflict of Interest

The Authors declare that they have no conflict of interest.

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Authors' Contributions

A.K., G.Z., B.B. treated the patients and designed the study; A.K., D.Č., Đ.D., K.AT., I.D. contributed to the design and implementation of the research, to the analysis of the results and the writing of the manuscript; B.B., A.N., Đ.D., and A.K analyzed the recent literature and took part in writing the manuscript. All authors have read and agreed to the published version of the manuscript.

Data Availability

The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request.

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