ORIGINAL RESEARCH

Random Forest Model for Labor Induction in Pregnant Women With Hypertensive Disorders Using a Cervical Double Balloon

Kehua Huang, MM; Zhaozhen Liu, MM; Jinying Luo, MD; Xiaoling Li, MM; Jianying Yan, MM

ABSTRACT

Context • Women with hypertensive disorders of pregnancy often need to have labor induced. The use of cervical double balloons to trigger cervical ripening, combined with the use of oxytocin, has been widely used for labor induction in recent years. In the evaluation of factors affecting the success rate of labor induction, previous predictive models have been limited to use of linear correlation, which simplifies the complex relationship between a large number of variables.

Objective • The study intended to retrospectively analyze the factors influencing the outcomes of cervical dilatation using a cervical double balloon in the induction of labor for pregnant women with hypertensive disorders and to establish a predictive model based on the random forest (RF) method that is able to manage multifeatured data, provide fast training speeds, offer high predictive accuracy, and analyze the impact of various features.

Design • The research team performed a retrospective analysis of data.

Setting • The study took place at the Fujian Provincial Maternity and Child Health Hospital at the Affiliated Hospital of Fujian Medical University in Fuzhou, China.

Participants • Participants were 201 women in late pregnancy who came to the hospital for delivery between January 2014 and December 2018, who had hypertensive disorders of pregnancy, and for whom doctors induced labor using a cervical double balloon.

Intervention • The research team divided participants into an intervention group, who had a successful induced labor, and a control group, who had a failed induced labor.

Outcome Measures • The research team analyzed the medical records of the groups using the RF method of ensemble learning and the multifactor logical regression method. The team used the receiver operating characteristic curve (ROC) to evaluate the working efficiency of the two models. The RF prediction model examined the factors influencing induced labor: the pregnancy method, the ultrasound EFW, the amniotic fluid index (AFI), the serum LDH level of the pregnant women, the placental volume, the cervical Bishop score before use of the balloon, the duration of the balloon's use, and the hours of use of oxytocin after balloon removal.

Results • The success rate for induced labor with use of a cervical double balloon for women with hypertensive disorders during pregnancy was 77.18%. The incidence of postpartum hemorrhage was 4.7% and of fetal distress was 12.7%. The most important 10 features were: (1) hours of oxytocin use, (2) fetal weight, (3) placental volume, (4) AFI, (5) LDH, (6) BMI, (7) the Bishop score before use of the COOK balloon, (8) duration of the balloon's use, (9) pregnancy method, and (10) weight gain during pregnancy. The area under the ROC curve for successful induction for the RF model was 0.983. The multivariate logistic regression model based on RF showed that multiple births, high cervical Bishop scores before labor induction, less time for use of oxytocin after balloon removal, and a small placental volume were independent risk factors, with the area under the ROC curve for successful induction being 0.918.

Conclusions • Medical practitioners can use the cervical double balloon effectively for the induction of labor for women with hypertensive disorders during the third trimester of pregnancy, and the prediction model for induction of labor based on RF had a good working efficiency. (*Altern Ther Health Med.* 2023;29(1):44-51).

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Hypertensive disorders during pregnancy are a unique group of diseases, with an incidence rate of 5% to 12% worldwide.[1] This group of diseases seriously affects the health of mothers and infants and is one of the main causes of maternal and perinatal deaths worldwide.

Most women with these disorders don't have cervical conditions matured enough for delivery, and this condition can be coupled with systemic arteriole spasm, reduced uterine, placental blood flow, and a susceptibility to fetal distress. The disorders often require early termination of a pregnancy due to negative indications for the mother or fetus. They aren't an absolute indication of the need for a cesarean section, but the benefits of early termination of pregnancy for these patients are often greater than waiting for spontaneous delivery.

Choosing the appropriate timing and method of termination of a pregnancy to obtain good maternal and infant outcomes has always been a major challenge in the field of obstetrics.[1] Vaginal delivery can avoid the risks of cesarean section, but often problems exist, such as the fetus being far from full term or the mother having an immature cervix.

Women with hypertensive disorders of pregnancy often need to have labor induced, and induction can increase the rate of vaginal delivery. Therefore, it's very important to choose an appropriate method of induction and to evaluate the success rate of that method in a timely manner.

Factors Affecting Labor Induction

Due to the risks of uterine rupture, fetal distress, and failure to induce labor, which can increase the rate of cesarean section, adequate evaluation before labor induction is an important step to improve the success rate of labor induction and reduce the risks to mother and child.

Weight gain during pregnancy. Xu et al found that weight gain during pregnancy above the average level, for women who have normal weights or those who are overweight or obese, is associated with an increased risk of cesarean section, but not for women who are underweight.[2] The relationship between weight gain during pregnancy and either elective cesarean section or emergency cesarean section is similar. However, among obese women, an above-average weight gain is associated with an increased risk of emergency cesarean section. Therefore, doctors recommend that pregnant women limit excessive weight gain to reduce the risk of cesarean section.

Body mass index (BMI). Bushman et al found that fetuses with higher weights tend to have mothers with a higher BMI than fetuses with lower weights.[3] Those mothers with a higher BMI were more likely to undergo cesarean section if the fetus' weight, as estimated by ultrasound, was larger than that estimated by abdominal examination. Therefore, the results of estimation of fetal weight (EFW) using ultrasound on the induction of labor is not only related to the weight of the fetus and the progress of labor but also is closely related to the psychology of pregnant women.

Multiparous and primiparous women. Denona et al found that the successful induction of labor for multiparous women was significantly higher than that for primiparous women.[4] This probably occurs because the compliance of the soft birth canal for multiparous women is better than that for primiparous women, and the effects of the cervical ripening by double-balloon treatment is more obvious. It's also probably related to primiparous women's inability to tolerate a long labor.

Assisted reproductive technology (ART). Vannuccini et al found that women who conceive using ART have a higher risk of spontaneous abortion, and that babies conceived through ART have a lower incidence of prolonged labor, especially of the prolonged active stage, but showed a higher risk of surgical delivery.[5] This may be because the women with ART fetuses have had trouble conceiving, and the pregnant women and medical staff are less likely to accept the risks of delivery.

Lighter placenta. In the past, Warkentin indicated that a lighter placenta could be related to a decrease of placental water volume and placental insufficiency.[6] This relative placental insufficiency also could result in decreased amniotic fluid and fetal weight. The reduction of the tension of the uterine wall is a prerequisite for enhanced coordination of activities before delivery, making the placenta lighter and the start of delivery easier.

Lactic dehydrogenase (LDH). LDH is a major intracellular cytoplasmic enzyme. When a cell ruptures or becomes damaged, the original tissue releases LDH, which enters the blood circulation. Since the LDH activity of most tissues is hundreds of times higher than that of normal serum, even if a small amount of tissue decomposition occurs, serum LDH can significantly increase.[7]

Changes in LDH activity in the uterine muscle during pregnancy and possibly during the entire delivery period may contribute to effective uterine activity during delivery. Neal et al confirmed that a significant correlation existed between the rate of cervical dilation in the first four hours after delivery and serum LDH after delivery.[8]

Cervical Balloons and Oxytocin

A multicenter randomized controlled study found that the fetus is more likely to suffocate from placental dysfunction during cervical ripening with dinoprostone than with mechanically induced ripening.[9] The use of cervical double balloons to trigger cervical ripening, combined with the use of oxytocin, has been widely used for labor induction in recent years, including for pregnant women with hypertension during pregnancy. Wang et al compared the cervical Bishop scores before and after placement of cervical double-balloons and found that they increased the cervical ripening in induction of labor in delayed pregnancy.[10]

The balloon's mechanism is likely to be regulated by changes in the local endocrine environment of hormones and by immune signals. Sciscione found that the mechanical stretching force of the cervix stimulates the amniotic membrane to increase the synthesis of prostaglandin E2 (PGE2), and the stretching of muscle cells can lead to the upregulation of the prostaglandin biosynthesis mediator, cyclooxygenase-2 (COX-2).[11] The cervical double-balloon mainly causes the cervix to soften, the cervical canal to recede, and cervical dilatation to occur through mechanical and hormonal effects.

Cervical double balloons often need to be combined with oxytocin to induce effective uterine contractions. Girault et al and Mussi et al found that prolonging the use of oxytocin during labor might increase adverse maternal and child outcomes, such as neonatal asphyxia, neonatal acidosis, emergency cesarean section rate, and postpartum hemorrhage.[12,13]

Random Forest Model

Levine et al indicated that the factors affecting the success rate of labor induction include such factors as maternal age, height, and weight; parity, the number of times a woman has given birth to a fetus with a gestational age of 24 weeks or more, regardless of whether the child was born alive or was stillborn; cervical maturity; gestational age; and fetal size.[14] However, those researchers found that previous prediction models have been limited to use of linear correlation, which simplifies the complex relationship between a large number of variables, making it difficult to meet clinical needs and lacking application in clinics.

Although a variety of factors can affect the success of labor induction, evaluation of factors separately isn't enough to accurately assess the probability of successful labor induction for a woman. Therefore, establishing a robust predictive model is very necessary to evaluate the success rate of labor induction.

In the past, researchers have completed a lot of work in this area. They have established some predictive models for different groups of people and adopted different methods. For example, as mentioned above, Vannuccini et al showed that the ultrasound cervical scoring system provided more predictive results than the manual cervical Bishop score in predicting the outcome of induced labor.[15] However, other studies have pointed out that doctors should consider other maternal and fetal characteristics, such as the mother's BMI, weight gain during pregnancy, fetal position, and parity, before labor induction.

Levine et al created a predictive model for cesarean section in women with a full-term singleton pregnancy.[16] That study used a multifactor logistic model, which found that primipara status, gestational age ≥ 40 weeks, BMI before delivery, modified Bishop score, and height of the women were significantly related to cesarean section. After evaluation, the area under the ROC curve of the model was 0.73.

Liu et al applied six representative machine-learning algorithms to build prediction models to predict early pregnancy loss after in-vitro fertilization and embryo transfer, including analysis using logistic regression (LR); support vector machines (SVMs), decision trees (DTs); back propagation in neural networks (BNN); XGBoost, an open-source software library; and Random Forest (RF).[17] Those researchers found that the RF model performed better than other models.

The RF model is a relatively new machine-learning model, which is characterized by its ability to manage multifeatured data, provide fast training speeds, offer high predictive accuracy, and analyze the impact of various features, helping to improve disease risk prediction and disease assessment. It's an ensemble learning model based on a decision tree, the classification and regression tree (CART).

The model is an efficient and accurate data-mining method that relies on computers and is based on multiple decision trees. It can evaluate all the complex and nonlinear interactions between variables, making the observed results consistent and minimizing the errors between prediction results. Researchers can achieve higher prediction accuracy through Bootstrap aggregation and randomization of predictors.

Tetschke used LR and RF models to assess fetal maturation age using heart-rate-variability measures and found that the average prediction of gestational age was better using RF than linear multiple regression. On the other hand, Xiao et al found that LR was more accurate and had better anti-interference ability against complexity indicators than RF.[18]

Current Study

The current study intended to retrospectively analyze the factors influencing the outcomes of cervical dilatation using a cervical double balloon in the induction of labor for pregnant women with hypertensive disorders and to establish a predictive model based on the RF method that is able to manage multifeatured data, provide fast training speeds, offer high predictive accuracy, and analyze the impact of various features.

METHODS

Participants

The research team performed a retrospective analysis of data. The study took place at the Fujian Provincial Maternity and Child Health Hospital at the Affiliated Hospital of Fujian Medical University in Fuzhou, China. Potential participants were 4004 women in late pregnancy with hypertensive disorders who came to the hospital for delivery between January 2014 and December 2018. All women undergoing delivery at the hospital receive prenatal examinations at its outpatient clinic at approximately 28 to 42 weeks of pregnancy.

Potential participants were included in the study if: (1) the pregnancy was their first, (2) they had unbroken membranes at the start of delivery, (3) the fetal head presentation was for delivery, (4) the estimated fetal mass was less than 4000 g, (5) their pelvis was normal, and (5) they were willing to have a vaginal delivery.

Potential participants were excluded from the study if they had had surgical complications during labor.

Of the 3083 potential participants not included in the study. The research team obtained written informed consent from all participants whom the research team selected for inclusion in the study. The Ethics Committee of the hospital approved the study's protocols.

Procedures

Balloon insertion. All of the participants' doctors had chosen a cervical double balloon to induce labor. The doctors checked participants' vaginal and cervical secretions before labor induction and performed the insertion of the balloon in about 20 min under aseptic conditions. The procedure used a balloon from Cook Medical (Bloomington, IN, USA).

In the insertion, the doctor: (1) inserts the double balloon into the cervical canal until it passes through the canal; (2) injects 20 ml of 0.9% sodium-chloride solution into the uterine balloon and pulls it outward so that the balloon is close to the cervix; (3) with the vaginal balloon at the outer opening of the cervix and the solution injected, removes the speculum; (4) then sequentially injects the uterine and vaginal balloons with 20 ml per time of the solution until both balloons have 80 ml each; and (5) with the double balloon exposed, fixes the vaginal part of the catheter on the woman's inner thigh, allowing her to move freely.

When uterine contractions start, the uterine orifice opens naturally, the water sac falls off, and labor begins. If premature rupture of the membranes occurs, the doctor removes the balloon immediately; otherwise, the doctor removes the balloon 12 hours later and measure the cervical Bishop score again. If no regular contractions occur, the doctor continues to give a small dose of oxytocin intravenously until regular contractions occur, stopping the oxytocin titration at more than 2 cm away from the uterine opening. The doctor routinely monitors the woman's blood pressure, and ECG monitoring occurs as appropriate after the woman enters labor.

Groups. The research team divided participants into an intervention group, who had a successful induced labor, and a control group, who had a failed induced labor.

Data collection. The research team collected participants' clinical data using the hospital's electronic medical-record system: (1) general information, such as age, blood pressure, weight gain during pregnancy, body mass index (BMI), number of births (parity), weeks of pregnancy, and past medical history; (2) relevant laboratory results before induction of labor, such as blood sugar, blood lipids, platelet parameters, liver and kidney function, coagulation index, inflammation indicators, and cervical secretion culture; (3) maternal complications and outcomes for the mother and child, such as premature rupture of membranes, premature placental abruption, postpartum hemorrhage, fetal distress, oligohydramnios, fetal growth restriction, disseminated intravascular coagulation (DIC), hemolysis-increased liver transaminase-thrombocytopenia syndrome (HELLP), intensive-care-unit (ICU) occupancy, chorioamnionitis, fetal distress, stillbirth, fetal malformation, newborn's birth weight, newborn's gender, Apgar score, newborn's transfer to neonatal intensive care unit (NICU), neonatal respiratory distress syndrome, neonatal pneumonia, neonatal brain injury, and cerebral hemorrhage; and (4) placental conditions, such as the placenta's weight and size and pathology results.

RF prediction model. Through bootstrap resampling technology, an investigator randomly selects multiple samples from an original sample set of data, and in each sample, includes the same number of pieces of data as the original set has, and replaces to form a sample subset. The investigator uses each sample subset to construct a decision tree and then merges the prediction results from multiple decision trees.

In the RF self-sampling process, the investigator uses only two-thirds of the samples of the initial training set when establishing each decision tree and uses the remaining one-third of the samples as the validation set to perform out-of-package estimation to perform the generalization. This one-third, called out-of-bag, can replace the test set for error estimation.

The investigator optimizes the model by optimizing the number of decision trees (ntree) and the number of split variables (mtry). The F1 score measures the model's accuracy. The model has the function of evaluating the importance of features. The higher the feature's importance score, the greater the impact that the feature has on the classification results. The investigator further analyzes the more important variables in the model using multi-factor logistic regression and then establishes a model.

The number of meta-classification trees of the RF model and the maximum depth of the tree can affect the accuracy of the model. For the current study, the research team specified the depth and number of the RF model tree as follows: max depth (2, 3, 4, 5, 6) and number of estimators (1, 2, 3, 4, 5, 6, 7, 8, 9, 10).

Outcome measures. The maternal delivery method was the main measure, with a successful induction of labor being defined as vaginal delivery after labor induction. The research team defined failure to induce labor as the occurrence of longer durations of the latent phase—up to 24 hours or longer—and the need to administer oxytocin for at least 12-18 hours after membrane rupture and delivery by cesarean section.[19]

The research team measured the pregnancy outcomes and factors influencing induced labor and identified the independent risk factors and calculated area under the ROC curve.

Outcome Measures

Pregnancy outcomes. For the mothers, the research team measured the rates of postpartum hemorrhage, ICU occupancy, placental abruption, and intrauterine infection and the amount of postpartum hemorrhage in the first 2 hours. For the newborns, the research team measured the neonatal weight and the rates of NICU occupancy, neonatal asphyxia, neonatal jaundice, neonatal septicemia, neonatal respiratory distress syndrome, neonatal pneumonia, and ischemic hypoxic myocardial damage.

Factors influencing induced labor. The research team measured the rates of use of natural conception and conception with ART, the ultrasound EFW, the AFI, the LDH, the placenta volume, the Bishop score before COOK balloon, the balloon duration, and the hours of use of oxytocin after balloon removal.

Predictive variables. The research team identified the independent risk factors that finally entered the logistic regression model.

Area under the ROC curve. To predict the successful induction of labor, the research team calculated area under the ROC curve for the multivariate logistic regression model.

Statistical Analysis

The research team analyzed the data using SPSS 25.0 statistical software (IBM Corp, Armonk, NY, USA) and the R language, a language and environment for statistical computing and graphics. The team expressed measurement data: (1) for normal distributions as means ± standard deviation (SDs) and performed comparisons between the groups using two independent samples *t* tests and (2) for non-normal distributions, expressed the data as medians and quartiles [M(Q1, Q3)], and used the Mann-Whitney U rank sum test for comparison between groups. The team expressed the count data as rates, using the chi-square test or Fisher's exact probability test.

The research team used the ROC curve to evaluate the working efficiency of the RF model and the multifactor logistic regression model. $P < .05$ indicated that a difference was statistically significant.

Figure 1. The Participants' Flow Through the Trial

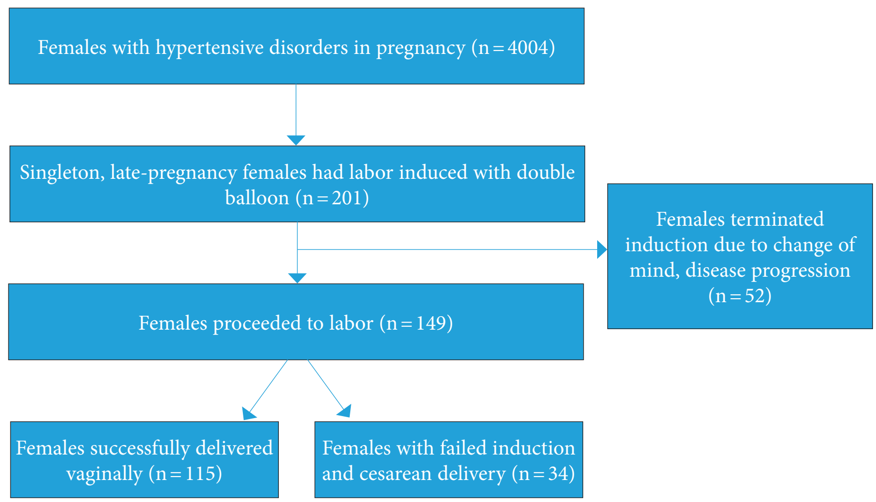


Table 1. Demographic and Clinical Characteristics of Patients with Hypertension Undergoing Induction of Labor (N = 149)

Item	Intervention Group n = 115 Mean ± SD n (%)	Control Group n = 34 Mean ± SD n (%)	χ^2/t	P value
Age, y	29.042 ± 4.896	29.564 ± 3.855	0.564	.574
Systolic blood pressure, mmHg	132.771 ± 11.603	136.973 ± 15.428	1.715	.089
Diastolic blood pressure, mmHg	85.831 ± 9.532	89.242 ± 10.357	1.792	.075
Gestational age, wks	38.608 ± 2.465	38.656 ± 1.436	0.108	.914
Number of births			11.453	.003[a]
0	61 (53.04)	29 (85.29)		
≥1	54 (46.96)	5 (14.71)		
Weight gain during pregnancy, kg	12.365 ± 3.997	14.013 ± 4.813	2.013	.046[a]
BMI on admission, kg/m2	27.063 ± 3.452	28.766 ± 3.464	2.525	.013[a]

[a]*P* < .05, indicating that the number of participants in the intervention group who had had one or more prior births was significantly larger than that of the control group, and the weight gain during pregnancy and BMI at admission were significantly lower in the intervention group than in the control group

Abbreviations: BMI, body mass index.

RESULTS

Figure 1 shows the participants' flow through the trial. The study included and analyzed the data of 201 participant, 115 in the intervention group and 34 in the control group. Another 52 participants were initially included in the study but their data were excluded from analysis because the women didn't meet the conditions for induction failure or the doctors terminated their pregnancies using cesarean section because they changed their minds about having natural childbirth, fetal distress had occurred, or the women's hypertension had progressed.

Participants ranged in age from 20 to 42 years. The mean age in the intervention group was 29.042 ± 4.896 and in the control group was 29.564 ± 3.855 (Table 1). No statistically significant differences existed between the groups in age or systolic or diastolic blood pressure at baseline before induction.

At baseline before labor induction, the number of participants in the intervention group who had had one or more prior births was significantly larger than that of the control group ($P < .003$), while weight gain during pregnancy and BMI at admission were significantly lower in the intervention group than in the control group, with $P = .046$ and $P = .013$, respectively.

Pregnancy Outcomes for the Mother and Child

Table 2 shows that no significant differences existed between the groups in the rates of postpartum hemorrhage, placental abruption, or intrauterine infection ($P \geq .05$). However, the rate of intensive care unit (ICU) occupancy was significantly higher and the amount of vaginal bleeding in the first two hours was significantly lower in the intervention group than in the control group, with $P = .010$ and $P = .000$, respectively.

Table 2. Pregnancy Outcomes for the Mother and Child (N = 149)

Item	Intervention Group n = 115 Mean ± SD n (%)	Control Group n = 34 Mean ± SD n (%)	χ^2/t	*P* value
Postpartum hemorrhage	6 (5.22)	1 (2.94)	0.304	.582
ICU occupancy	13 (11.30)	10 (29.41)	6.591	.010[a]
Postpartum hemorrhage in first 2 hours	231.901 ± 253.430	431.562 ± 108.050	4.467	.000[a]
Placental abruption	7 (6.08)	1 (2.94)	0.511	.475
Intrauterine infection	5 (4.35)	3 (8.82)	1.035	.309
Neonatal weight	3007.371 ± 624.246	3225.03 ± 405.157	2.401	.019[a]
NICU occupancy	13 (11.30)	3 (8.82)	0.168	.681
Neonatal asphyxia	1 (0.87)	0 (0.00)	0.298	.585
Neonatal jaundice	28 (24.35)	9 (26.47)	0.063	.801
Neonatal septicemia	1 (0.87)	0 (0.00)	0.298	.585
Neonatal respiratory distress syndrome	1 (0.87)	0 (0.00)	0.298	.585
Neonatal pneumonia	5 (4.35)	1 (2.94)	0.134	.714
Ischemic hypoxic myocardial damage	6 (5.22)	0 (0.00)	1.848	.174

[a]*P* < .05, indicating that the rate of intensive care unit (ICU) occupancy was significantly higher and the amount of vaginal bleeding in the first two hours was significantly lower for the mothers in the intervention group than those in the control group, and the weights of the newborns in the intervention group were significantly lower than those of the control group

Abbreviations: ICU, intensive care unit; NICU, newborn intensive care unit.

Table 3. Factors Influencing Induced Labor With Cervical Double Balloon (N = 149)

Item	Intervention Group n = 115 Mean ± SD n (%)	Control Group n = 34 Mean ± SD n (%)	χ^2/t	*P* value
Pregnancy methods			6.857	.032[a]
Natural conception	115 (100.00)	32 (94.12)		
Conception with ART	0 (0.00)	2 (5.88)		
Ultrasound EFW	3080.81 ± 573.210	3385.6 ± 377.681	2.915	.004[a]
AFI, cm	12.637 ± 3.253	11.124 ± 4.0294	2.252	.026[a]
LDH, U/L	266.487 ± 168.987	218.394 ± 94.668	2.126	.036[a]
Placenta volume, cm^2	582.433 ± 234.333	732.324 ± 241.073	3.255	.001[a]
Bishop score before COOK balloon	3.530 ± 1.172	2.851 ± 0.702	-4.166	.000[a]
Balloon duration	11.326 ± 2.726	12.559 ± 1.812	3.070	.003[a]
Hours of use of oxytocin after balloon removal	8.500 ± 6.028	17.906 ± 11.329	6.383	.000[a]

*P < .05, indicating that: (1) the Bishop scores for the cervix before the double balloon's placement were significantly greater, (2) the Doppler ultrasound EFW and placenta volume were significantly smaller, (3) the duration of the placement of the cervical double balloon and the hours of use of oxytocin were significantly shorter, (4) the AFI and LDH were significantly greater, and (5) the number of participants conceiving with ART were significantly smaller, for the intervention group than for the control group

Abbreviations: AFI, amniotic fluid index; ART, assisted reproductive technology; EFW, estimated fetal weight; LDH, lactic dehydrogenase.

In the intervention group, the newborns' weights were significantly lower than those of the control group (P = .019). No statistically significant differences existed between the groups in the rates of neonatal admission to the newborn intensive care unit (NICU) or in other complications, including neonatal asphyxia, neonatal jaundice, neonatal sepsis, neonatal respiratory distress syndrome, neonatal pneumonia, or neonatal ischemic hypoxic myocardial injury ($P \geq .05$).

Factors Influencing Induced Labor

Table 3 shows that the Bishop scores for the cervix before the double balloon's placement were 3.530 ± 1.172 for the intervention group and 2.851 ± 0.702 for the control group (t=27.926, P = .000). After placement, the scores were 6.279 ± 1.064 for the intervention group and for the control group (data not shown). The posterior cervical ripening rate was 77.11%, and the success rate for induction was 77.18% (data not shown).

The Doppler ultrasound estimated fetus weight (EFW) and placenta volume in the intervention group were significantly smaller than those of the control group, with P = .004 and P = .001, respectively. The duration of the placement of the cervical double balloon and the hours of use of oxytocin in the intervention group were significantly shorter than those in the control group, with P = .003 and P = .000.

The intervention group's amniotic fluid index (AFI), and serum LDH were significantly greater than those of the control group, with P = .026 and 0.036, respectively. Significantly more participants in the control group had conceived with ART than did participants in the intervention group (P = .032).

Predictive Variables

After the model cross-matching, the maximum depth of the decision tree was 5 and the number of estimators was 3; the accuracy of the model was the highest, with the f1-score being 0.8262. At this time, the model's complexity and effect reached a balance. Therefore, in the RF model in the current study, the maximum depth of the decision trees was 5, and the number of trees was 3.

Figure 2 shows the evaluation of the importance of the features for the model. The most important 10 features were: (1) hours of oxytocin use, (2) fetal weight, (3) placental volume, (4) AFI, (5) LDH, (6) BMI, (7) the Bishop score before use of the COOK balloon, (8) duration of the balloon's use, (9) pregnancy method, and (10) weight gain during pregnancy.

Table 4 shows that the additional processing of the variables in the RF model into a multifactor logistic regression analysis indicated that the independent risk factors that finally entered the logistic regression model were: (1) number of births ($P=.002$), (2) the Bishop score of the cervix before labor induction ($P=.001$), (3) the duration of oxytocin after balloon removal ($P=.000$), and (4) the placenta volume ($P=.000$).

Favorable factors for successful induction of labor were: (1) multiple births, (2) high cervical scores before labor induction, (3) less time for use of oxytocin after balloon removal, and (4) small placental volume.

ROC Curve

The area under the ROC curve for the multivariate logistic regression model was 0.918, and the area under the ROC curve for the RF model was 0.983 (Figure 3). No statistically significant difference existed between the two predicted values ($t=1.38$, $P=.17$).

DISCUSSION

The doctors of the participants in the current study used double balloons to promote cervical ripening. Comparing the cervical bishop scores before and after balloon placement showed that the cervical double balloons promoted a cervical ripening rate of 77.11%, which is similar to Wan et al's finding[10] related to the induction of labor in delayed pregnancy. The current study also showed a vaginal delivery rate of 77.18%.

The current research team expects that the predictive model they developed can help doctors to clinically evaluate the conditions of pregnant women for induction of labor more comprehensively and reduce the cesarean section and adverse maternal and child outcomes caused by improper labor induction.

Two previous studies found that prolonged use of oxytocin during labor can increase adverse maternal and child outcomes,[12,13] and the use of

Figure 2. Feature Importance of Random Forest Model

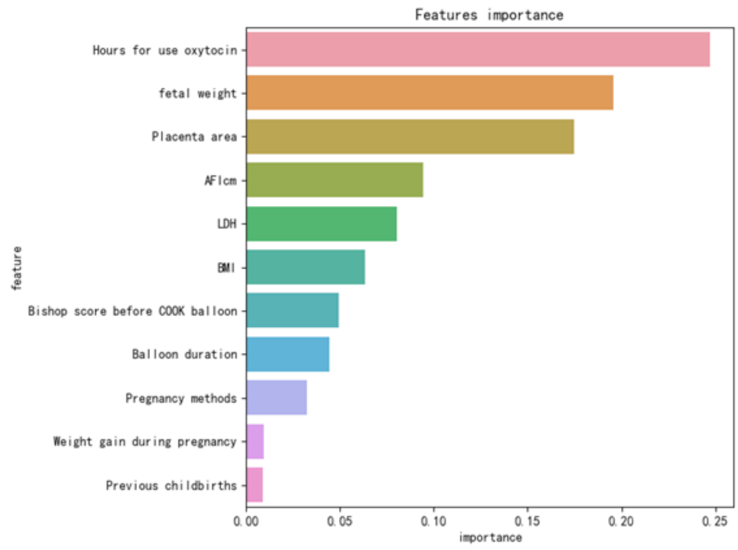
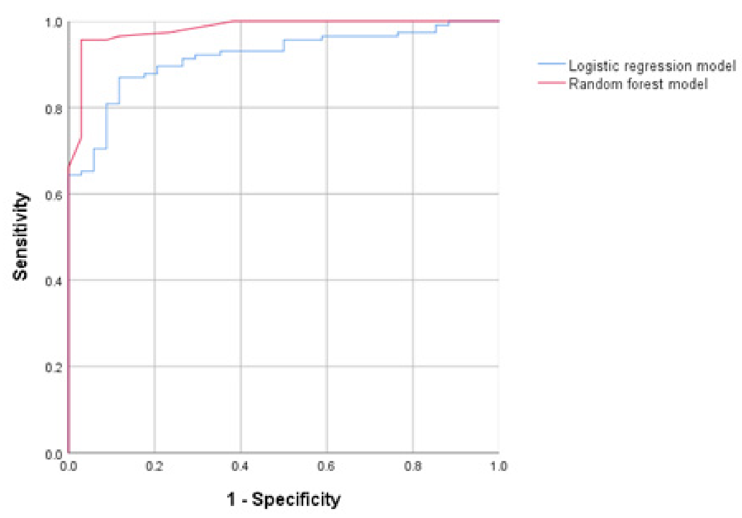


Table 4. Predictive Variables Comprising Logistic Regression Model

Characteristic	B	SE	Wald	*P* value	OR	95% CI
Number of births	2.301	0.759	9.191	.002[a]	9.986	2.256-44.209
Bishop score before COOK balloon	1.067	0.324	10.849	.001[a]	2.908	1.541-5.487
Hours of use of oxytocin after balloon removal	-0.196	0.043	20.882	.000[a]	0.822	0.756-0.894
Placenta volume	-0.004	0.001	12.268	.000[a]	0.996	0.994-0.998

[a]$P<.05$, indicating that the independent risk factors that finally entered the logistic regression model were the number of births, the Bishop score of the cervix before labor induction, the duration of oxytocin after balloon removal, and the placenta volume

Figure 3. ROC Curves of Testing Samples in the Two Prediction Models



oxytocin in the current study's intervention group was lower than that of the control group after the doctors took the balloons out. This suggests that prolonging the use of oxytocin doesn't increase the success rate of labor induction. Timely assessment and treatment can avoid blindly prolonging the time of oxytocin induction in pursuit of a vaginal delivery rate.

In addition, the placenta volume of the intervention group in the current study was smaller than that of the control group. The current study validated Warkentin's theory[13] that a smaller placenta may be more conducive to successful induction of labor.

The multivariate logistic regression model predicted that the area under the ROC curve for successful labor induction would be 0.918. It was slightly lower than that of the RF model. It may be that the logistic regression model included fewer factors than the RF model and wasn't comprehensive enough. Some factors that were more important in the RF model, such as fetal weight, AFI, LDH, and BMI weren't included in the logistic model, so its work efficiency was slightly inferior to the RF model. However, no statistically significant difference existed in the statistical analysis of the predicted value of the two models, which shows that the multifactor RF logistic model also has good practical value.

In the current study, the RF algorithm analyzed all factors related to pregnant women's prenatal examination and delivery time, detected the interaction effects between the factors, and screened out important variables to establish a predictive model, thus making the predictive ability of the model more accurate. When doctors obtain the data required by the predictive model in the clinic, they can use the model to assess the success rate of pregnancy in pregnant women with hypertensive disorders of pregnancy in a timely manner, which can help clinicians to make timely and accurate judgments and guide clinical treatment to reduce adverse maternal and child outcomes.

The limitations of the present study were as follows: (1) the study was a single-center, retrospective study; (2) the intervention group had more participants than the control group; and (3) other factors may have affected induced labor with a cervical double balloon that the research team didn't analyze.

CONCLUSIONS

Medical practitioners can use the cervical double balloon effectively for the induction of labor for women with hypertensive disorders during the third trimester of pregnancy, and the prediction model for induction of labor based on RF had a good working efficiency.

AUTHORS' DISCLOSURE STATEMENT

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AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

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