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The value of the combined MR imaging features and clinical factors Nomogram model in predicting intractable postpartum hemorrhage due to placenta accreta

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Abstract

To explore the value of the combined MR imaging features and clinical factors Nomogram model in predicting intractable postpartum hemorrhage (IPH) due to placenta accreta (PA). We conducted a retrospective study with 270 cases of PA patients admitted to our hospital from January 2015 to December 2022. The clinical data of these patients were analyzed, and they were divided into 2 groups: the IPH group and the non-IPH group based on the presence of IPH. The differences in data between the 2 groups were compared, and the risk factors for IPH were analyzed. A Nomogram model was constructed using independent high-risk factors, and the predictive value of this model for IPH was analyzed. The results of multivariable binary Logistic regression analysis showed higher number of cesareans, placenta previa, placenta accreta type (implantation, penetration), low signal strip on T2 weighted image (T2WI) were independent high-risk factor for IPH ($P < .05$). ROC analysis and Hosmer-Lemeshow goodness-of-fit test showed the Nomogram predictive model constructed with the high-risk factor has good discrimination and calibration. Decision curve analysis (DCA) showed that when the probability threshold for the Nomogram model's prediction was in the range from 0.125 to 0.99, IPH patients could obtain more net benefits, making it suitable for clinical application. The higher number of cesareans, placenta previa, placental accreta type (implantation, penetration), and low signal strip on T2WI are independent high-risk factor for IPH. The Nomogram predictive model constructed with the high-risk factor demonstrates good clinical efficacy in predicting the occurrence of IPH due to PA.

Abbreviations: DCA = decision curve analysis, IPH = intractable postpartum hemorrhage, PA = placenta accreta, ROC = receiver operating characteristic, T2WI = T2 weighted image.

Keywords: intractable postpartum hemorrhage, MR, Nomogram model, placenta accreta

1. Introduction

Placenta accreta (PA) is one of the critical conditions in clinical obstetrics, often leading to excessive bleeding in postpartum and being a significant cause of emergency hysterectomy.[1] PA refers to the occurrence of deficient or abnormal development of the uterine endometrium at the site of placental implantation, resulting in direct invasion of villi into the uterine myometrium, even deep layers of the myometrium, leading to abnormal placental implantation.[2] Postpartum hemorrhage refers to the shedding of the uterine endometrium after delivery, accompanied by a significant loss of blood. Normally, the uterus contracts to reduce bleeding, and blood clot formation helps with hemostasis. However, in some cases, this process may become uncontrolled, leading to excessive bleeding. Intractable postpartum hemorrhage (IPH) refers to severe bleeding that cannot be effectively controlled or stopped by conventional measures. The causes of IPH may include PA, inadequate uterine contractions, uterine

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All patients had given informed consent.

The authors have no conflicts of interest to disclose.

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

This study was approved by the Ethics Committee of Affiliated Maternity and Child Health Care Hospital of Nantong University.

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fibroids, retained placenta, and endometriosis. Additionally, injuries or complications during delivery or surgery can also result IPH.[3–5]

PA is one of the important causes of IPH. Due to abnormal invasion of the placenta into the uterine muscle layer, normal uterine contraction and blood vessel contraction mechanisms are disrupted, leading to ineffective control of postpartum bleeding. Especially after delivery or cesarean section, the placenta may not be smoothly separated, which can easily cause severe and persistent bleeding.[6,7] IPH poses a great threat to the life of the mother and requires emergency intervention and appropriate treatment. For patients with PA, emergency surgeries such as hysterectomy may be necessary to stop bleeding and save the mother's life.[8,9] Early diagnosis and identification of risk factors

Table 1

The differences in patient data between the 2 groups.

Variable	Total (n = 270)	IPH		Statistic	*P*
		No (n = 139)	Yes (n = 131)		
Age, M (Q_1, Q_3)	31.00 (28.00–34.00)	30.00 (27.50–33.00)	32.00 (29.00–34.00)	Z = −2.200	.028
Number of miscarriages, M (Q_1, Q_3)	1.00 (0.00–2.00)	1.00 (0.00–2.00)	1.00 (0.50–2.00)	Z = −1.869	.062
Number of cesareans, M (Q_1, Q_3)	1.00 (0.00–1.00)	0.00 (0.00–1.00)	1.00 (0.00–1.00)	Z = −4.477	<.001
Placenta previa, n (%)				χ^2 = 23.712	<.001
No	48 (17.78)	40 (28.78)	8 (6.11)		
Yes	222 (82.22)	99 (71.22)	123 (93.89)		
Placenta accreta types, n (%)				χ^2 = 55.252	<.001
Adhesion	119 (44.07)	89 (64.03)	30 (22.90)		
Implantation	133 (49.26)	50 (35.97)	83 (63.36)		
Penetration	18 (6.67)	0 (0.00)	18 (13.74)		
Spontaneous delivery of the placenta, n (%)				χ^2 = 5.159	.023
No	175 (64.81)	99 (71.22)	76 (58.02)		
Yes	95 (35.19)	40 (28.78)	55 (41.98)		
History of intrauterine operation, n (%)				χ^2 = 0.348	.555
No	248 (91.85)	129 (92.81)	119 (90.84)		
Yes	22 (8.15)	10 (7.19)	12 (9.16)		
Cesarean scar pregnancy, n (%)				χ^2 = 1.723	.189
No	264 (97.78)	138 (99.28)	126 (96.18)		
Yes	6 (2.22)	1 (0.72)	5 (3.82)		
History of placenta previa, n (%)				χ^2 = 0.000	1.000
No	267 (98.89)	137 (98.56)	130 (99.24)		
Yes	3 (1.11)	2 (1.44)	1 (0.76)		
History of ectopic pregnancy, n (%)				χ^2 = 0.715	.398
No	263 (97.41)	137 (98.56)	126 (96.18)		
Yes	7 (2.59)	2 (1.44)	5 (3.82)		
Labor induction, n (%)				χ^2 = 0.969	.325
No	256 (94.81)	130 (93.53)	126 (96.18)		
Yes	14 (5.19)	9 (6.47)	5 (3.82)		
Antepartum hemorrhage, n (%)				χ^2 = 3.136	.077
No	157 (58.15)	88 (63.31)	69 (52.67)		
Yes	113 (41.85)	51 (36.69)	62 (47.33)		
Abdominal pain, n (%)				χ^2 = 0.064	.800
No	244 (90.37)	125 (89.93)	119 (90.84)		
Yes	26 (9.63)	14 (10.07)	12 (9.16)		
Low strip signal on T2WI, n (%)				χ^2 = 23.910	<.001
No	39 (14.44)	29 (20.86)	10 (7.63)		
4–6 strips	126 (46.67)	67 (48.20)	59 (45.04)		
1–3 strips	71 (26.3)	37 (26.62)	34 (25.95)		
Diffuse	34 (12.59)	6 (4.32)	28 (21.37)		
Myometrial thinning, n (%)				χ^2 = 19.103	<.001
No	79 (29.26)	57 (41.01)	22 (16.79)		
Yes	191 (70.74)	82 (58.99)	109 (83.21)		
Myometrial interruption, n (%)				χ^2 = 11.557	<.001
No	138 (51.11)	85 (61.15)	53 (40.46)		
Yes	132 (48.89)	54 (38.85)	78 (59.54)		
Disappearance of the post placental clear space, n (%)				χ^2 = 0.887	.346
No	23 (8.52)	14 (10.07)	9 (6.87)		
Yes	247 (91.48)	125 (89.93)	122 (93.13)		
Abnormal subplacental vascularity, n (%)				χ^2 = 17.287	<.001
No	70 (25.93)	51 (36.69)	19 (14.50)		
Yes	200 (74.07)	88 (63.31)	112 (85.50)		
Unclear boundary of bladder, n (%)				χ^2 = 12.770	<.001
No	255 (94.44)	138 (99.28)	117 (89.31)		
Yes	15 (5.56)	1 (0.72)	14 (10.69)		
Hysterocele, n (%)				χ^2 = 29.246	<.001
No	199 (73.7)	122 (87.77)	77 (58.78)		
Yes	71 (26.3)	17 (12.23)	54 (41.22)		

IPH = intractable postpartum hemorrhage, T2WI = T2 weighted image.

for IPH, as well as planning postpartum management plans in advance, are crucial in preventing the occurrence of intractable postpartum hemorrhage. Therefore, this study aimed to explore the value of the combined MR imaging features and clinical factors Nomogram model in predicting IPH due to PA and provide preliminary basis for the prevention and treatment of IPH.

2. Methods

2.1. Patients

We conducted a retrospective study with 270 cases of PA patients admitted to our hospital from January 2015 to December 2022, and they were divided into 2 groups: the IPH group and the non-IPH group based on the presence of IPH. Inclusion criteria: Patients with complete clinical data, who underwent prenatal ultrasound and MR examination, and confirmed PA by surgery or pathology. Exclusion criteria: Claustrophobia; Contraindications to MR examination; Maternal complications during pregnancy; Placental abnormalities; Uterine abnormalities; and Coagulation dysfunction. Patient's baseline data were showed in Table 1. Patient's clinical baseline data included age, placenta previa, placental invasion types, spontaneous delivery of the placenta, number of miscarriages, number of cesareans, history of intrauterine operation, cesarean scar pregnancy, history of placenta previa, history of ectopic pregnancy, labor induction, antepartum hemorrhage, abdominal pain, intractable postpartum hemorrhage.

2.2. MR detection

The SIMENSAvanto 1.5T superconducting MR scanner was used, with a 6-channel phased-array body surface coil for detection. Patients were positioned in a supine or left lateral position. All patients underwent a plain scan. During the examination, pregnant women were instructed to breathe calmly and were not required to hold their breath. The scanning range extended from the symphysis pubis to 2cm above the uterine fundus. The scanning sequences and parameters can be found in Table 2.

2.3. MR image analysis

Two senior physicians independently analyzed the images, both of whom have been involved in placenta implantation diagnosis for more than 2 years. They observed the signs under the T2 weighted image (T2WI)-HASTE MR fast scanning sequence: Low signal strip on T2WI, myometrial thinning, myometrial interruption, disappearance of the post-placental clear space, abnormal subplacental vascularity, unclear boundary of bladder, hysterocele. If their appraisal results are inconsistent, please ask senior physicians with more experience to identify and unify the results.

2.4. Statistics processing

The measurement data obtained in this study did not conform to a normal distribution according to the Kolmogorov-Smirnov D test. It was represented by the median (interquartile range), and group comparisons were performed using the Mann-Whitney U rank-sum test. The count data was expressed as the number of cases (percentage), and group comparisons were conducted using the chi-square test. Binary unconditional logistic regression model was used to identify the related risk

Table 2

Univariable binary logistic regression analysis.

Variables	Beta	S.E.	*Z*	*P*	OR (95% CI)
Age	0.05	0.03	1.76	.079	1.05 (0.99–1.11)
Number of cesareans	0.86	0.20	4.18	<.001	2.35 (1.57–3.52)
Placenta previa					
Yes					(Reference)
No	−1.83	0.41	−4.45	<.001	0.16 (0.07–0.36)
Placenta accreta types					
Adhesion					(Reference)
Implantation	1.59	0.28	5.76	<.001	4.92 (2.86–8.47)
Penetration	1.87	0.93	2.02	.009	12.62 (6.70 -11.36)
Spontaneous delivery of the placenta					
Yes					(Reference)
No	−0.58	0.26	−2.26	.024	0.56 (0.34–0.93)
Low signal s trip on T2WI					
No					(Reference)
4–6 strips	0.98	0.44	2.24	.025	2.66 (1.13–6.27)
1–3 strips	0.94	0.41	2.30	.022	2.55 (1.15–5.68)
Diffuse	2.61	0.58	4.49	<.001	13.53 (4.34–42.21)
Myometrial thinning					
No					(Reference)
Yes	1.24	0.29	4.26	<.001	3.44 (1.95–6.09)
Myometrial interruption					
No					(Reference)
Yes	0.84	0.25	3.37	<.001	2.32 (1.42–3.77)
Abnormal subplacental vascularity.					
No					(Reference)
Yes	1.23	0.30	4.04	<.001	3.42 (1.88–6.20)
Unclear boundary of bladder					
No					(Reference)
Yes	2.80	1.04	2.69	.007	16.51 (2.14–127.46)
Hysterocele					
No					(Reference)
Yes	1.62	0.31	5.15	<.001	5.03 (2.72–9.31)

T2WI = T2 weighted image.

factors for IPH through univariate analysis, and a multivariate analysis was conducted to determine the independent high-risk factors, which were then used to construct a Nomogram model. The clinical effectiveness of the Nomogram model in predicting IPH occurrence was evaluated using receiver operating characteristic (ROC) curve, Hosmer-Lemeshow goodness-of-fit test, calibration curve, and decision curve analysis (DCA).

3. Results

3.1. The differences in patient data between the 2 groups

The age, number of cesareans, proportion of placenta previa, proportion of placenta accreta type (implantation, penetration), proportion of diffuse low signal strip on T2WI, proportion of myometrial thinning, proportion of myometrial interruption, proportion of abnormal subplacental vascularity, proportion of unclear boundary of bladder, proportion of hysterocele in the IPH group were higher than that in non-IPH group ($P < .05$). The proportion of spontaneous delivery of the placenta of IPH group was lower than that of non-IPH group ($P < .05$). The differences in other data between groups were not significant ($P > .05$). The results were showed in the Table 1.

3.2. Risk factors of IPH

The results of univariable binary Logistic regression analysis showed higher number of cesareans, placenta previa, placenta accreta type (implantation, penetration), low signal strip on T2WI, myometrial thinning, myometrial interruption, abnormal subplacental vascularity, unclear boundary of bladder, hysterocele were the related risk factors of IPH ($P < .05$). The results of multivariable binary Logistic regression analysis showed higher number of cesareans, placenta previa, placenta accreta type (implantation, penetration), low signal strip on T2WI were independent high-risk factor for IPH ($P < .05$). The results were showed in the Table 2,3.

3.3. The construction of the Nomogram model and the evaluation of its clinical effectiveness

The regression equation was used to construct a Nomogram predictive model with the abovementioned independent high-risk factors for IPH (Fig. 1A), when the total point from the model was 26-70, the risk for IPH was 0.10-0.90. ROC analysis showed that the area under the curve of the model for predicting IPH was 0.841 (0.794-0.888), with a sensitivity of 87.0% and specificity of 68.3% (Fig. 1B). The result of Hosmer-Lemeshow goodness-of-fit test showed $\chi 2 = 3.83$, $P = .87$, indicating that the Nomogram prediction model has good calibration. The calibration plot graphically showed good agreement between the IPH and the risk estimation by the nomogram with a mean absolute error of 0.017 (Fig. 1C). The result of the DCA analysis showed that when the probability threshold for the Nomogram model's prediction of IPH occurrence was in the range from 0.125 to 0.99, IPH patients could obtain more net benefits, making it suitable for clinical application (Fig. 1D).

4. Discussion

PA can cause severe postpartum hemorrhage in pregnant women. Therefore, PA patients may need to choose the

Table 3

Multivariable binary logistic regression analysis.

Variables	Beta	S.E.	*Z*	*P*	OR (95% CI)
Number of cesareans	0.75	0.26	2.85	.004	2.12 (1.27–3.56)
Placenta previa					
Yes					(Reference)
No	−2.53	0.58	−4.38	<.001	0.08 (0.03–0.25)
Placenta accreta types					
Adhesion					(Reference)
Implantation	1.34	0.33	4.02	<.001	3.81 (1.99–7.31)
Penetration	1.79	0.79	6.02	.008	6.42 (3.01–10.79)
Spontaneous delivery of the placenta					
Yes					(Reference)
No	−0.50	0.37	−1.34	.180	0.61 (0.29–1.26)
Low signal strip on T2WI					
No					(Reference)
4–6 strips	0.71	0.55	1.29	.196	2.03 (0.69–5.93)
1–3 strips	1.07	0.49	2.17	.030	2.93 (1.11–7.72)
Diffuse	2.18	0.81	2.70	.007	8.88 (1.82–43.21)
Myometrial thinning					
No					(Reference)
Yes	0.29	0.38	0.76	.445	1.33 (0.64–2.79)
Myometrial interruption					
No					(Reference)
Yes	−0.11	0.36	−0.29	.768	0.90 (0.44–1.82)
Abnormal subplacental vascularity.					
No					(Reference)
Yes	0.64	0.38	1.67	.095	1.90 (0.89–4.04)
Unclear boundary of bladder					
No					(Reference)
Yes	−0.13	1.23	−0.10	.919	0.88 (0.08–9.92)
Hysterocele					
No					(Reference)
Yes	0.28	0.41	0.69	.490	1.33 (0.59–2.98)

T2WI =T2 weighted image.

following hemostasis methods during the perinatal period, such as blood transfusion, intervention, and hysterectomy. PA is the main cause of hysterectomy in women of childbearing age.[10] In cesarean section, if there is clinical evidence of insufficient oxygen delivery or persistent bleeding, immediate blood transfusion is required. When there is moderate uterine bleeding, uterine artery embolization should be performed immediately after the patient's vital signs stabilize in cesarean section patients

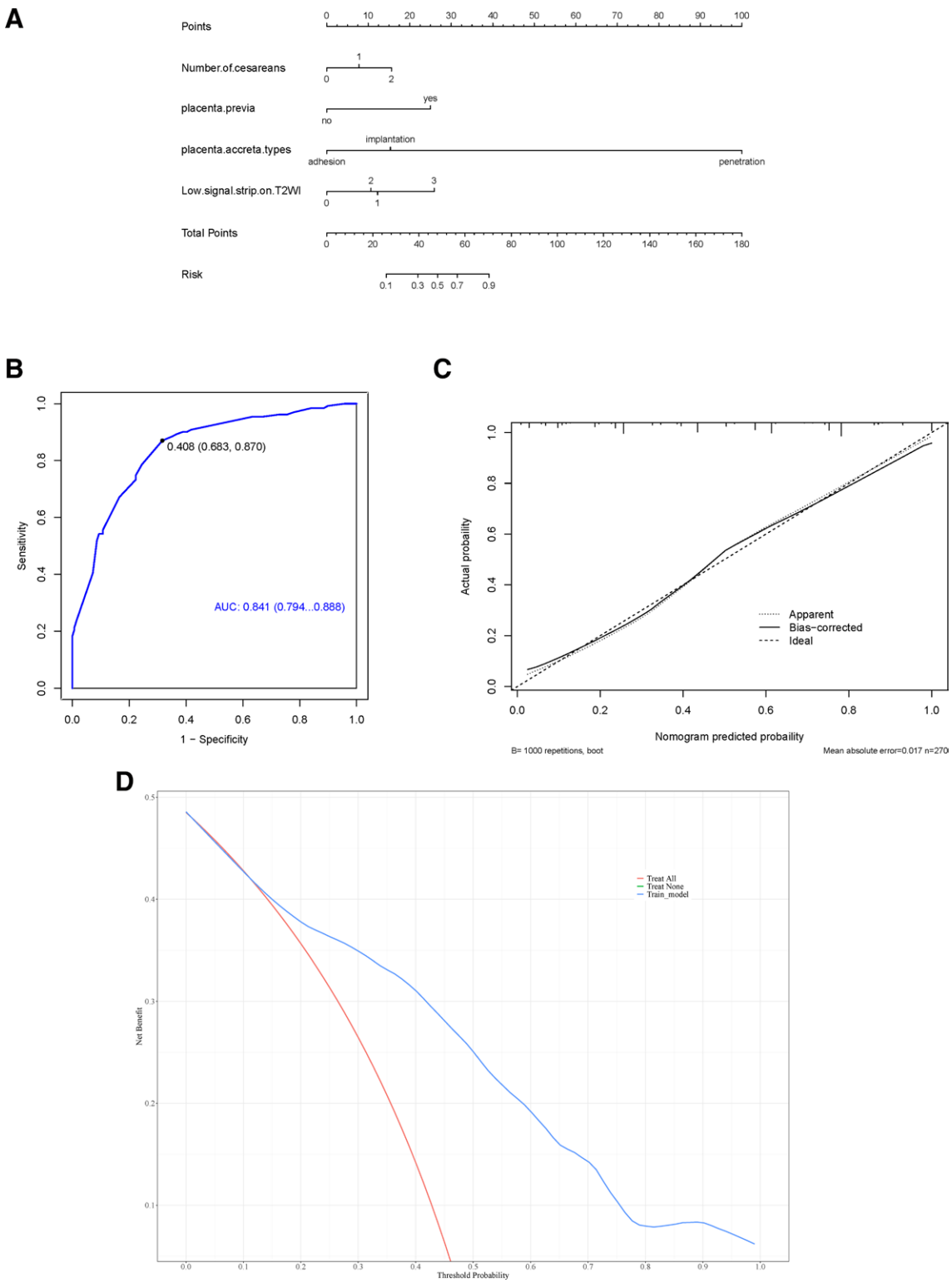

Figure 1. The construction of the Nomogram model and the evaluation of its clinical effectiveness. (A) The regression equation was used to construct a Nomogram predictive model with the abovementioned independent high-risk factors for IPH, when the total point from the model was 26–70, the risk for IPH was 0.10–0.90. (B) ROC analysis showed that the AUC of the model for predicting IPH was 0.841 (0.794–0.888), with a sensitivity of 87.0% and specificity of 68.3%. (C) The calibration plot graphically showed good agreement between the IPH and the risk estimation by the nomogram with a mean absolute error of 0.017. (D)The result of the DCA analysis showed that when the probability threshold for the Nomogram model's prediction of IPH occurrence was in the range from 0.125 to 0.99, IPH patients could obtain more net benefits, making it suitable for clinical application.

to control uterine bleeding. If extensive blood transfusion and hemostasis procedures have already been performed, and even uterine artery embolization fails to control massive uterine bleeding, and the patient's condition remains unstable, hysterectomy should be performed.[11] Therefore, early and accurate prediction of IPH is particularly important in guiding clinicians to choose appropriate surgical methods and take timely measures to address perinatal complications. Is it possible to predict IPH based on the imaging manifestations of PA and other clinical features of the patient? With the contemplation of this question, we conducted this study.

The results of this study showed higher number of cesareans, placenta previa, placenta accreta type (implantation, penetration), low signal strip on T2WI, myometrial thinning, myometrial interruption, abnormal subplacental vascularity, unclear boundary of bladder, hysterocele were the related risk factors of IPH, and higher number of cesareans, placenta previa, placenta accreta type (implantation, penetration), low signal strip on T2WI were independent high-risk factor for IPH.

Research has shown that multiple cesarean sections may increase the risk of IPH.[12,13] This is because cesarean section can result in uterine scar formation, and the number and repetition of scars may weaken the uterine muscle layer, thereby increasing the risk of postpartum bleeding. Multiple cesarean sections may further diminish the uterine contractile ability, leading to ineffective contractions and inadequate hemostasis, thereby increasing the incidence of IPH. Additionally, multiple cesarean sections may also contribute to the formation of pelvic adhesions, which can affect the normal anatomical structure of the uterus and other related tissues, thereby increasing the risk of postpartum hemorrhage. The risk of IPH is higher in cases of placenta previa.[14–16] Because placenta previa can result in the placenta being located near or covering the cervical opening, obstructing the normal birth canal. This increases the risk of detachment between the uterus and placenta during delivery, thus raising the possibility of postpartum bleeding. Placenta previa can also lead to ineffective contraction of the uterine muscles at the top of the uterus, and the lack of strong uterine contractions increases the risk of IPH. Additionally, placenta previa causes the placenta to be excessively close to the cervical opening, which can result in cervical lacerations and tears during delivery. These injuries can lead to more severe bleeding, further increasing the risk of IPH. Implantation placenta refers to the situation where the placenta partially or completely embeds into the uterine wall. In this case, the tissue connection between the placenta and the uterine wall is tighter, making it difficult to separate during delivery, which can easily lead to severe bleeding and increase the risk of IPH.[17] Penetration of the placenta accreta refers to the condition where the placenta penetrates through the uterine wall. This can result in tears in the uterine wall and heavy bleeding during delivery, thus increasing the incidence of IPH. Low signal strip on T2WI indicates abnormal blood flow within the placenta.

We used the regression equation to construct a Nomogram predictive model with the abovementioned independent high-risk factors for IPH when the total point from the model was 26-70, the risk for IPH was 0.10-0.90. ROC analysis showed that area under the curve of the model for predicting IPH was 0.841 (0.794-0.888), with a sensitivity of 87.0% and specificity of 68.3%. The result of Hosmer-Lemeshow goodness-of-fit test indicated that the Nomogram prediction model has good calibration. The calibration plot graphically showed good agreement between the IPH and the risk estimation by the nomogram with a mean absolute error of 0.017. The result of the DCA analysis showed that when the probability threshold for the Nomogram model's prediction of IPH occurrence was in the range from 0.125 to 0.99, IPH patients could obtain more net benefits, making it suitable for clinical application. However, this study is a single-center retrospective study and there has been no external validation of the Nomogram predictive model. We will address this limitation by conducting further external validation in subsequent multicenter studies. The significance of our research's Nomogram predictive model is primarily focused on the occurrence of IPH caused by placenta accreta. Recent studies[18–20] have reported the significance of related Nomogram predictive models for placenta accreta spectrum. They found Nomogram predictive model constructed with certain MRI imaging features and clinical characters have value in the prediction of placenta accreta spectrum. They have all undergone external validation, and reported similar results testing their Nomogram model in external validation group.

In summary, the higher number of cesareans, placenta previa, placental accreta type (implantation, penetration), and low signal strip on T2WI are independent high-risk factor for IPH. The Nomogram predictive model constructed with the high-risk factor demonstrates good clinical efficacy in predicting the occurrence of IPH due to PA.

Author contributions

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