MRI-Based Radiomics Nomogram To Predict Intraoperative Hemorrhage of Placenta Previa

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Abstract

Background: Placenta previa is associated with higher percentage of intraoperative and postpartum hemorrhage, increased obstetric hysterectomy, significant maternal morbidity and mortality. We aimed to develop and validate a magnetic resonance imaging (MRI)-based nomogram to preoperative prediction of intraoperative hemorrhage (IPH) for placenta previa, which might contribute to adequate assessment and preoperative preparation for the obstetricians.

Methods: Between May 2015 and December 2019, a total of 125 placenta previa pregnant women were divided into a training set (n = 80) and a validation set (n = 45). Radiomics features were extracted from MRI images of each patient. A MRI-based model comprising seven features was built for the classification of patients into IPH and non-IPH groups in a training set and validation set. Multivariate nomograms based on logistic regression analyses were built according to radiomics features. Receiver operating characteristic (ROC) curve was used to assess the model. Predictive accuracy of nomogram were assessed by calibration plots and decision curve analysis.

Results: In multivariate analysis, placenta position, placenta thickness, cervical blood sinus and placental signals in the cervix were signifcantly independent predictors for IPH (all $p < 0.05$). The MRI-based nomogram showed favorable discrimination between IPH and non-IPH groups. The calibration curve showed good agreement between the estimated and the actual probability of IPH. Decision curve analysis also showed a high clinical benefit across a wide range of probability thresholds. The AUC was 0.918 (95% CI, 0.857-0.979) in the training set and 0.866(95% CI, 0.748-0.985) in the validation set by the combination of four MRI features.

Conclusions: The MRI-based nomograms might be a useful tool for the preoperative prediction of IPH outcomes for placenta previa. Our study enables obstetricians to perform adequate preoperative evaluation to minimize blood loss and reduce the rate of caesarean hysterectomy.

Background

Placenta previa (PP) is characterized by the abnormal placenta overlying the lower uterine segment, and it is known as one of the most serious obstetric complication[1].The incidence of PP is about 3.5 to 4.6 per 1000 pregnancies[2]. The exact pathophysiology of PP is not exactly known. The incidence of PP and placenta accreta is increasing due to abortion, cesarean section and other uterine surgical history[3, 4]. PP is divided into four types according to the distance between the placenta and the cervix: low-lying placenta, marginal placenta, partial placenta and complete placenta previa[5]. PP is commonly diagnosed by ultrasound sonography or magnetic resonance imaging (MRI) in the third trimester[6]. Ultrasound is the preferred procedure for evaluting placental position and placenta accreta, but is limited in some cases, such as patients with abdominal fat hypertrophy and posterior placenta. MRI was used widely in recent years[7], which can clearly define the position of placenta and the situation of adjacent organs of uterus, and give doctors more detailed preoperative evaluation[8]. A large number of studies have shown that MRI has high sensitivity and specificity in the diagnosis of placenta accreta (sensitivity,82.2–100%; specificity, 84.0–100%)[9, 10]. Due to the thinning uterine segment, PP is often combined with placenta accreta or increta. PP and placenta accreta is associated with high incidence of intraoperative hemorrhage (IPH) and postpartum haemorrhage, need for blood transfusion and hysterectomy, which is considered a severe complication of pregnancy, and even death[11, 12, 13]. In addition, women with PP has a serious threat on fetal health, such as delivery premature, fetal distress, neonatal intensive care (NICU) admission, stillbirth and neonatal death[14]. In recent years, more scholars combined clinical data and imaging examination to predict the risk of IPH in patients with placenta previa. Choi and Yangyu respectively developed a model based on clinical and ultrasonic signs to predict IPH and the possibility of hysterectomy in patients with placenta previa [15, 16] .

Our hospital is a treatment center for high-risk pregnant women, and most of the pregnant women with PP around our hospital were referred to our hospital for delivery. Through the treatment of a large number of pregnant women with PP, we have accumulated some experience in treatment. A well planned multidisciplinary team approach could reduce IPH and minimize the potential risks of maternal mortality[17]. Thus, an accurate prenatal diagnosis and evaluation of PP is imperative. Hence, in this study, we sought to develop a MRI signature nomogram to predict IPH in patients with PP.

Methods

Patients selection

The Ethical Committee of the affiliated Suzhou hospital of Nanjing medical university approved the experimental protocol and waived the need for informed consent. All methods were carried out in accordance with relevant guidelines and regulations. All methods were carried out in accordance with relevant guidelines and regulations. Given the retrospective study and anonymous patient data, the requirement for informed consent was waived. A total of 125 consecutive patients with PP who were treated from May 2015 to December 2019 were enrolled in our study, according to the following inclusion criteria: (i) All pregnant women received regular prenatal examinations and deliveried in our hospital; (ii) Pelvic MRI was performed before caesarean section; (iii) availability of clinical characteristics. Patients excluded are those unable to undergo MRI (n=51), marginal placenta previa (n=92) and delivery in other hospitals (n=67). Finally, a total of 125 patients were enrolled in the study. All cases were C-section, emergent C-section was required when a pregnant woman has massive bleeding or obvious uterine contractions. In our study, 120 pregnant women had scheduled C-section and 5 cases had emergent C-section. Archived clinical data, such as age at the time of delivery, BMI, gestational age by MRI, amount of blood transfusion, operative time and caesarean hysterectomy were extracted from reviewing the medical records (Figure 1).

Standard of reference

Severe postpartum hemorrhage may occur in PP patients after removal of the placenta in cesarean section. Intraoperative blood loss is an important indicator of the severity of PP. Normal parturient can tolerate 1000 milliliters (ml) of blood loss, when the volume of blood loss is more than 2000 ml, the parturient may be in a state of shock, which will seriously threaten the life of parturient. We need a multidisciplinary approach to maternal rescue, so the cutoff value of IPH was set at 2000 ml in our study. The IPH group was defned as cesarean section with massive intraoperative bleeding ($\geq$ 2000 ml). The non-IPH group was defned as cesarean section with minor intraoperative bleeding (< 2000 ml).

MRI data acquisition

Before cesarean delivery, all patients were performed pelvic MRI using a 3.0 T MRI system (Siemens Medical Solutions, Erlangen, Germany). The imaging protocol included three plane (sagittal, coronal and axial) T1-weighted and T2-weighted images of the pelvis. MRI images were retrospectively interpreted by three experienced radiologists on reading PP MRI. The signs of PP were analyzed by MRI, an MRI model was constructed by using only the typical features extracted from the MRI. The thickness of the placenta was obtained on a plane close to the longest line of the cervix. We established a high risk table for MRI features of IPH, and radiologists evaluated MRI image according to the figure (Figure 2). Any disagreement in the process of interpretation was resolved by the senior radiologist. For convenience of clinical application, a MRI based nomogram was constructed from the logistic regression model to predict the risk of IPH.

Data analysis and statistics

The nomogram construction, calibration plots and decision curve analysis were done with R software (https://www.r-project.org/). Other statistical analysis was performed using SPSS 23.0 and a two sided *p*-value < 0.05 was considered

significant. The differences in continuous variables were analyzed by Kruskal-Wallis test, whereas the differences in the categorical variables were assessed by Pearson χ^2 test or Fisher exact test. Univariate and multivariate logistic regression analysis was performed to identify independent factors associated with IPH > 2000 ml. Multivariate logistic regression model was used to construct the nomograms. Feature selection and model construction were only performed on the training cohort, and the validation cohort only for evaluating the model performance.

Results

Clinical characteristics of the patients

Among the 125 patients, we analyzed 30 patients with IPH > 2000 ml and 95 patients without. The clinical characteristics of patients in the training set, validation set, IPH and non-IPH group were listed in Table 1 and Table 2. The training and validation sets were similar in terms of the baseline clinical characteristics ($p > 0.05$). Statistical differences were found between IPH and non-IPH group in gravidity, parity, GA at Delivery, amount of blood transfusion, operative time, IPH, caesarean hysterectomy and NICU admission ($p < 0.05$).

Table 1
Clinical characteristics of pregnant women with placenta previa.

	Training set(n=80)			Validation set(n=45)		
	IPH	Non-IPH	*p*-value	IPH	Non-IPH	*p*-value
Parameter	(n=19)	(n=61)		(n=11)	(n=34)	
Age at delivery(years)	32.95±2.95	31.26±4.35	0.119	32.64±4.48	32.00±3.91	0.653
BMI before delivery (kg/m^2)	27.71±4.20	25.94±2.91	0.099	26.46±4.75	25.91±4.07	0.713
Gravidity	4.00±1.60	3.13±1.20	0.013	5.45±4.32	3.29±1.71	0.020
Parity	2.32±0.58	1.85±0.57	0.003	2.27±0.65	1.71±0.46	0.003
GA at Delivery (week)	34.91±1.07	35.60±1.20	0.001	35.68±0.70	36.67±0.83	0.001
GA by MRI (week)	34.75±2.28	33.71±2.41	0.099	34.40±1.06	34.73±1.80	0.573
Previous uterine surgery						
Caesarean section	14(73.68%)	32(52.46%)	0.102	7(63.64%)	18(52.94%)	0.535
Dilatation and curettage	6(31.58%)	12(19.67%)	0.278	3(27.27%)	7(20.59%)	0.643
Myomectomy	2(10.53%)	5(8.20%)	0.754	2(18.18%)	2(5.88%)	0.213
Previous placenta pervia	1(5.26%)	1(1.64%)	0.377	2(18.18%)	1(2.94%)	0.078
Amount of blood transfusion (ml)	2682.89±674.21	689.21±259.02	<0.001	2439.08±583.67	703.52±269.25	<0.001
Operative time	121.21±44.30	57.36±19.81	<0.001	125.36±27.43	51.76±13.56	<0.001
IPH (ml)	3814.73±1289.12	877.05±540.41	<0.001	3904.55±1035.00	817.65±461.70	<0.001
Placenta accreta	11(57.89%)	8(13.11%)	<0.001	6(54.55%)	4(11.76%)	0.003
Caesarean hysterectomy	1(5.26%)	0(0.00%)	<0.001	1(9.09%)	0(0.00%)	<0.001
Birth Weight(gram)	2907.89±379.06	2762.30±340.18	0.117	2772.73±455.17	2730.88±393.51	0.769
APGAR Score						
1st. Min	9.58±0.77	9.82±0.53	0.128	9.64±0.67	9.91±0.38	0.095
5th. Min	9.68±0.67	9.90±0.30	0.186	9.82±0.40	9.97±0.17	0.081

	Training set(n=80)			Validation set(n=45)		
Neonatal outcome						
NICU admission	13(68.42%)	25(40.98%)	0.037	7(63.64%)	10(29.41%)	0.042

Table 2
Magnetic resonance imaging metrics of placental structure for the training and validation sets.

	Training set(n=80)			Validation set(n=45)		
	IPH	Non-IPH	*p*-value	IPH	Non-IPH	*p*-value
Parameter	(n=19)	(n=61)		(n=11)	(n=34)	
Placenta position			<0.001			0.002
Anterior	17(89.47%)	24(39.34%)		9(81.82%)	10(29.41%)	
Posterior	2(10.53%)	37(60.66%)		2(18.18%)	24(70.59%)	
Placenta thickness	5.553±1.122	4.326±1.342	0.001	5.583±1.187	4.254±1.238	0.003
Bladder line			<0.001			0.007
Complete	7(36.84%)	50(81.97%)		4(36.36%)	27(79.41%)	
Incomplete	12(63.16%)	11(18.03%)		7(63.64%)	7(20.59%)	
Placenta pit			<0.001			0.001
Yes	12(63.16%)	8(13.11%)		7(63.64%)	5(14.71%)	
No	7(36.84%)	53(86.89%)		4(36.36%)	29(85.29%)	
Cervical blood sinus			<0.001			0.025
Yes	13(68.42%)	4(6.56%)		7(63.64%)	9(26.47%)	
No	6(31.58%)	57(93.44%)		4(36.36%)	25(73.53%)	
Cervical form			<0.001			0.014
Complete	7(36.84%)	54(88.52%)		4(36.36%)	26(76.47%)	
Incomplete	12(63.16%)	7(11.48%)		7(63.64%)	8(23.53%)	
Placental signals in the cervix			<0.001			<0.001
Yes	13(68.42%)	5(8.20%)		7(63.64%)	3(8.82%)	
No	6(31.58%)	56(91.80%)		4(36.36%)	31(91.18%)	

Performance of the radiomics signature

There was a significant difference in radiomics signatures between IPH and non-IPH patients in the training set ($p < 0.05$) and validation set ($p < 0.05$), which indicates the radiomics signatures were related to the IPH (Table 2). The univariate and multivariate model was constructed using the radiomics signature in the training cohort. On univariable analyses, placenta position, placenta thickness, bladder line, placental pit, cervical blood sinus, cervical form and placental signals in the cervix on MRI emerged as predictors of IPH (all $p < 0.05$). All of these covariates were included in a multivariable

logistic regression model. Placenta position, placenta thickness, cervical blood sinus and placental signals in the cervix on MRI emerged as predictors for the outcome of IPH on multivariable analysis($p < 0.05$) (Table 3).

Table 3
Univariate and multivariate regression analyses of the indicators for intraoperative hemorrhage in the training cohort

	Univariate			**Multivariate**		
Indicatiors	OR	95%CI	*p*-value	OR	95%CI	*p*-value
Placenta position	5.181	2.038-13.857	0.003	3.026	1.001-7.447	**0.012**
Placenta thickness	2.238	1.300-3.850	0.004	3.546	1.437-8.749	**0.016**
Bladder line	3.012	0.953-7.823	0.021	2.776	0.405-7.010	0.298
Placental pit	4.818	1.487-15.612	0.009	0.705	0.082-6.090	0.751
Cervical blood sinus	5.169	1.365-19.572	0.016	7.519	1.654-15.626	**0.019**
Cervical form	3.560	1.023-12.393	0.046	0.580	0.053-3.341	0.656
Placental signals in the cervix	7.361	2.29-23.664	0.001	10.913	1.934-19.935	**0.001**

Performance of the nomogram

Based on the above multivariate analysis results, the nomogram was constructed. In Figure 3, the nomogram shows the impact on the probability of IPH contributed by placenta position, placenta thickness, cervical blood sinus and placental signals in the cervix. By determining the score from all variables on a total point scale, probabilities of IPH(IPH > 2000 ml) could be determined by drawing a vertical line to the total score (Figure 3).

Receiver operating characteristic curve analysis and internal validation

The discriminatory ability of the nomogram for predicting IPH was investigated by ROC curves (Figure 4A, B). The combination of four MRI features model yielded an AUC of 0.918 (95% CI, 0.857-0.979) in the training set, with an accuracy of 87.9%, and an AUC of 0.866(95% CI, 0.748-0.985) in the validation set, with an accuracy of 85.3%. The specificity and sensitivity were 80.3% and 89.5% in the training set and 77.8% and 86.1% in the validation set (Table 4).

Table 4
Performance of models for IPH prediction.

Set	Model	AUC	Sensitivity(%)	Specificity(%)	Accuracy(%)
Training Set	Placenta position	0.693(0.551-0.835)	76.3(63.6-86.1)	62.0(37.2-82.4)	67.5(61.2-74.1)
	Placenta thickness	0.713(0.573-0.852)	75.4(62.7-85.5)	63.2(38.4-83.6)	64.5(59.4-70.2)
	Cervical blood sinus	0.696(0.544-0.847)	91.8(81.9-97.3)	47.4(24.5-71.1)	70.5(58.6-83.9)
	Placental signals in the cervix	0.750(0.610-0.890)	86.9(75.8-94.1)	63.2(38.4-83.6)	76.8(69.8-84.8)
	Four MRI features	0.918(0.857-0.979)	80.3(68.2-89.4)	89.5(66.8-98.4)	87.9(78.5-95.6)
Validation Set	Placenta position	0.733(0.566-0.899)	64.7(46.5-80.2)	81.8(48.2-97.2)	65.8(51.6-78.0)
	Placenta thickness	0.787(0.640-0.934)	82.4(65.5-93.2)	63.6(30.9-88.8)	70.3(61.5-83.7)
	Cervical blood sinus	0.686(0.498-0.874)	73.5(55.6-87.1)	63.6(30.9-88.8)	64.8(58.6-71.5)
	Placental signals in the cervix	0.715(0.529-0.902)	79.4(62.1-91.3)	62.1(29.8-87.7)	78.7(66.5-89.6)
	Four MRI features	0.866(0.748-0.985)	77.8(65.5-88.6)	86.1(78.7-96.5)	85.3(73.6-96.5)

Two calibration plots were constructed in order to measure the fit between the predicted rate and the actual outcome. The calibration curve of the nomogram showed good calibration in the training and validation sets (Figure 5A, B). The decision curve analysis for evaluating the clinical utility of the predictive model were plotted, which showed favorable performance of the radiomics nomogram in the training and validation sets. This reflected greater benefit for the PP patients by MRI-based nomogram in the prediction of IPH (IPH > 2000 ml) if the threshold probability was greater than 0. 3 (Figure 6).

Discussion

Multiple abortions and intrauterine procedures may damage the endometrium, and placental villi can penetrate the myometrium, leading to placental implantation. Previous cesarean section is an independent risk factor for PP and placenta implantation[18]. The normal placenta is attached to the decidua basalis of the uterus, and the placenta can be removed smoothly after delivery. PP is often accompanied by placental percreta, in which villi penetrate through the entire myometrial thickness or surrounding organs[19]. When the placenta inserted into the myometrium is removed, the local myometrium is missing and leading to massive bleeding. The damage of myometrial by the placental increta is responsible for maternal bleeding and potential fetal compromise[20]. PP often leads to uncontrolled bleeding during childbirth or postpartum, which can cause serious consequences, even life-threatening. About 40-60% of the peripartum hysterectomies are due to placenta increta[21]. The IPH group had a higher NICU admission, mainly due to cesarean sections at a smaller gestational age in IPH group. Therefore, prenatal diagnosis of placental implantation and prediction of intraoperative blood loss can help clinicians make adequate preoperative preparation, develop appropriate surgical procedures and avoid serious complications.

Although ultrasound is an important method for the diagnosis of PP, MRI has been used more and more in the diagnosis and treatment of PP in recent years[22, 23], which fully demonstrates its value in the evaluation of intraoperative blood loss of PP. The aim of our study was to investigate the role of MRI for the PP diagnosis and the clinical prediction in IPH. Our current study included 125 cases of PP at high risk of co-existing placental accreta. When the patient underwent MRI examination, it was better to have about 400 ml of urine in the bladder, which was beneficial to predict whether the placental tissue was implanted into the bladder. In this study, blood loss was measured by using weighed swabs, which is more precise than methods using visual estimation. Patients with PP have more intraoperative bleeding due to the intense bleeding of the uterus during delivery of the placenta, especially those with the placenta located entirely in the lower uterine segment. Placental implantation can cause the placenta and uterine wall contact closely, postpartum placenta is not easy to peel and affect the uterine contraction, resulting in uterine blood sinus can not be closed and postpartum hemorrhage.

In MRI images, the typical shadowing characteristics of placenta implantation include thinning of the myometrium, placental penetration into the cervix, and uneven placental signals. Interruption of myometrium signal and placental invasion into pelvic tissues and organs are the most direct manifestations of placental implantation in MRI. However, due to the thinning of myometrium in the third trimester of pregnancy, the above features are lack of sensitivity and difficult to visualize, so they are rarely used in clinical diagnosis[24]. In this study, indirect signs (palcenta position, placenta thickness, bladder line, and placenta pit, etc.) were combined with the imaging characteristics of placenta previa for overall analysis, which was beneficial to improve the reliability of clinical diagnosis. Our study demonstrated that placental position, placental thickness, cervical blood sinus and placental signals in the cervix were independent predictors in predicting the risk of IPH. The intraplacental blood sinuses may be an overgrowth of the placenta and inserted into the myometrium[25]. Our study found that placental signal in the cervix (OR = 10.913) and cervical blood sinus (OR = 7.519) are the two major MRI signs at high risk of intraperitoneal bleeding, because it may indicate placental implantation in the cervix. Anterior to the lower segment of the uterus is the bladder, left and right ureters, and posterior to the rectum, which presents a great challenge to the operation of hemostasis in the cervix. An increase in the thickness of the placenta usually indicates that the placenta's blood supply is abundant, even implanted in the uterine wall. The placenta anteriorum is another risk factor for intrapartum bleeding, especially in pregnant women with a history of cesarean section. The placenta is easily implanted and can even penetrate the bladder, causing intrapartum bleeding and bladder damage.

Our study indicated that MRI-based nomogram could provide a non-invasive way to predict the risk of IPH in PP, which was confirmed by calibration and decision curve analyses. Our study showed that combining multiple MRI features has higher diagnostic value than a single feature, with high AUCs in the training and validation set. If a pregnant woman has a high risk score, abdominal aorta, common iliac artery balloon occlusion and other procedures may be selected for cesarean section. All cesarean sections in PP patients were performed by professional senior physicians, and thus had a lower hysterectomy rate (1.60%). The majority of newborns in the IPH group were transferred to the NICU, mainly due to the higher rate of premature births in this group. The nomogram of the combined model might be an effective and easy-to-use tool to estimate the danger level of PP before surgery, and patients might be given adequate preoperative evaluation and preoperative communication.

Despite the promising results, our study also had several limitations. Firstly, Our retrospective data were collected from a single unit for training and validating the predictive model. Secondly, our sample size is small, so we still need to increase the sample size for verification.

Conclusions

Based on these preliminary data of this study, we conclude that the MRI-based nomogram can assess the risk of intraoperative bleeding of placenta previa, enabling obstetricians to make adequate preoperative preparations, minimize intraoperative bleeding and ensure the health of mother and child. However, retrospective and prospective studies are still needed to confirm and optimize its predictive properties in the future.

Abbreviations

IPH: intraoperative hemorrhage; MRI: magnetic resonance imaging; NICU: neonatal intensive care; PP: Placenta previa; ROC: Receiver operating characteristic.

Declarations

Acknowledgments

Not applicable.

Authors' Contributions

YFY designed the study, and drafting/revision of the manuscript. LPZ (Liping Zhu) as the operation guide for cesarean section. YS made contributions to the acquisition of clinical study data. YML, DLC and QX analysed the imaging data. LPZ (Liping Zhou) and YDG made substantial contributions to the analysis and interpretation of data.

Founding

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing Interests

The authors declare no competing interests.

References

1. Silver RM. Abnormal Placentation: Placenta Previa, Vasa Previa, and Placenta Accreta[J]. Obstet Gynecol, 2015, 126(3):654–668.
2. Faiz AS, Ananth CV. Etiology and risk factors for placenta previa: an overview and meta-analysis of observational studies[J]. J Matern. Fetal Neonatal Med, 2003,13(3):175–190.

3. Belfort MA. Placenta accreta[J]. Am J Obstet Gynecol, 2010, 203(5):430–439.
4. Mary F Higgins, Cathy Monteith, Michael Foley, et al. Real increasing incidence of hysterectomy for placenta accreta following previous caesarean section[J]. Eur J Obstet Gynecol Reprod Biol, 2013,171(1): 54–56.
5. Oyelese Y, Smulian JC. Placenta previa, placenta accreta, and vasa previa[J]. Obstet Gynecol, 2006,107(4):927–941.
6. Ghourab S. Third-trimester transvaginal ultrasonography in placenta previa: does the shape of the lower placental edge predict clinical outcome? [J]. Ultrasound Obstet Gynecol, 2001;18(2):103–108.
7. Fadl S, Moshiri M, Fligner CL, et al. Placental Imaging Normal Appearance with Review of Pathologic Findings [J]. Radiographics, 2017, 37(3):979–998.
8. Lax A, Prince MR, Mennitt KW, et al. The value of specific MRI features in the evaluation of suspected placental invasion [J]. Magn Reson Imag, 2007,25(1):87–93.
9. Antonio FD, Iacovella C, Palacios-Jaraquemada J, et al. Prenatal identification of invasive placentation using magnetic resonance imaging: systematic review and meta-analysis[J]. Ultrasound Obstet Gynecol, 2014, 44(1):8–16.
10. Meng X, Xie L, Song W. Comparing the Diagnostic Value of Ultrasound and Magnetic Resonance Imaging for Placenta Accreta: A Systematic Review and Meta-analysis[J]. Ultrasound in Med Biol, 2013, 39(11):1958–1965.
11. Kollmann M, Gaulhofer J, Lang U, et al. Placenta praevia: incidence, risk factors and outcome [J]. J Matern Fetal Neonatal Med, 2013, 29(9):1395–1398.
12. Faranesh R, Romanov S, Shalev E, et al. Suggested approach for management of placenta percreta invading the urinary bladder [J]. Obstet Gynecol, 2007, 110(2):512–515.
13. Onwere C, Gurol-Urganci I, Cromwell DA, et al. Maternal morbidity associated with placenta praevia among women who had elective caesarean section [J]. Eur J Obstet Gynecol Reprod Biol, 2011, 159(1):62–66.
14. Schneiderman M, Balayla J. A comparative study of neonatal outcomes in placenta previa versus cesarean for other indication at term [J]. J Matern Fetal Neonatal Med, 2013,26(11):1121–1127.
15. Kim JW, Lee YK, Chin JH, et al. Development of a scoring system to predict massive postpartum transfusion in placenta previa totalis[J]. J Anesth 2017, 31(4):593–600.
16. Chong Y, Zhang Ai, Wang Y, et al. An ultrasonic scoring system to predict the prognosis of placenta accreta: A prospective cohort study. Medicine (Baltimore). 2018, 97(35):e12111.
17. John C Kingdom, Sebastian R Hobson, Ally Murji, et al. Minimizing surgical blood loss at cesarean hysterectomy for placenta previa with evidence of placenta increta or placenta percreta: the state of play in 2020[J]. Am J Obstet Gynecol, 2020,223(3):322–329.
18. Miller DA, Chollet JA, Goodwin TM. Clinical risk factors for placenta previa placenta accrete[J]. Am J Obstet Gynecol, 1997,177(1):210–214.
19. Bauer ST, Bonanno C. Abnormal Placentation [J]. Semin Perinatol, 2009,33(2):88–96.
20. Jauniaux E, Collins S, Burton GJ. Placenta accreta spectrum: pathophysiology and evidence-based anatomy for prenatal ultrasound imaging[J]. Am J Obstet Gynecol, 2018, 218(1): 75–87.
21. Arpe, SD, Franceschetti S, Corosu R, et al. Emergency peripartum hysterectomy in a tertiary teaching hospital: a 14-year review. Arch Gynecol Obstet, 2015, 291(4): 841–847.
22. Fadl S, Moshiri M, Fligner CL, et al. Placental Imaging: Normal Appearance with Review of Pathologic Findings[J]. Radiographics, 2017,37(3): 979–998.
23. Rahaim NS, Whitby EH. The MRI features of placental adhesion disorder and their diagnostic signifcance: systematic review[J]. Clin Radiol, 2015, 70(9): 917–925.

24. Baughman WC, Corteville JE, Shah RR. Placenta Accreta: Spectrum of US and MR Imaging Findings[J]. Radiographics, 2008, 28(7):1905–1916.
25. UenoY, Kitajima K, Kawakami F, et al. Novel MRI fnding for diagnosis of invasive placenta praevia: evaluation of findings for 65 patients using clinical and histopathological correlations[J]. Eur Radiol, 2014, 24(4): 881–888.

Figures

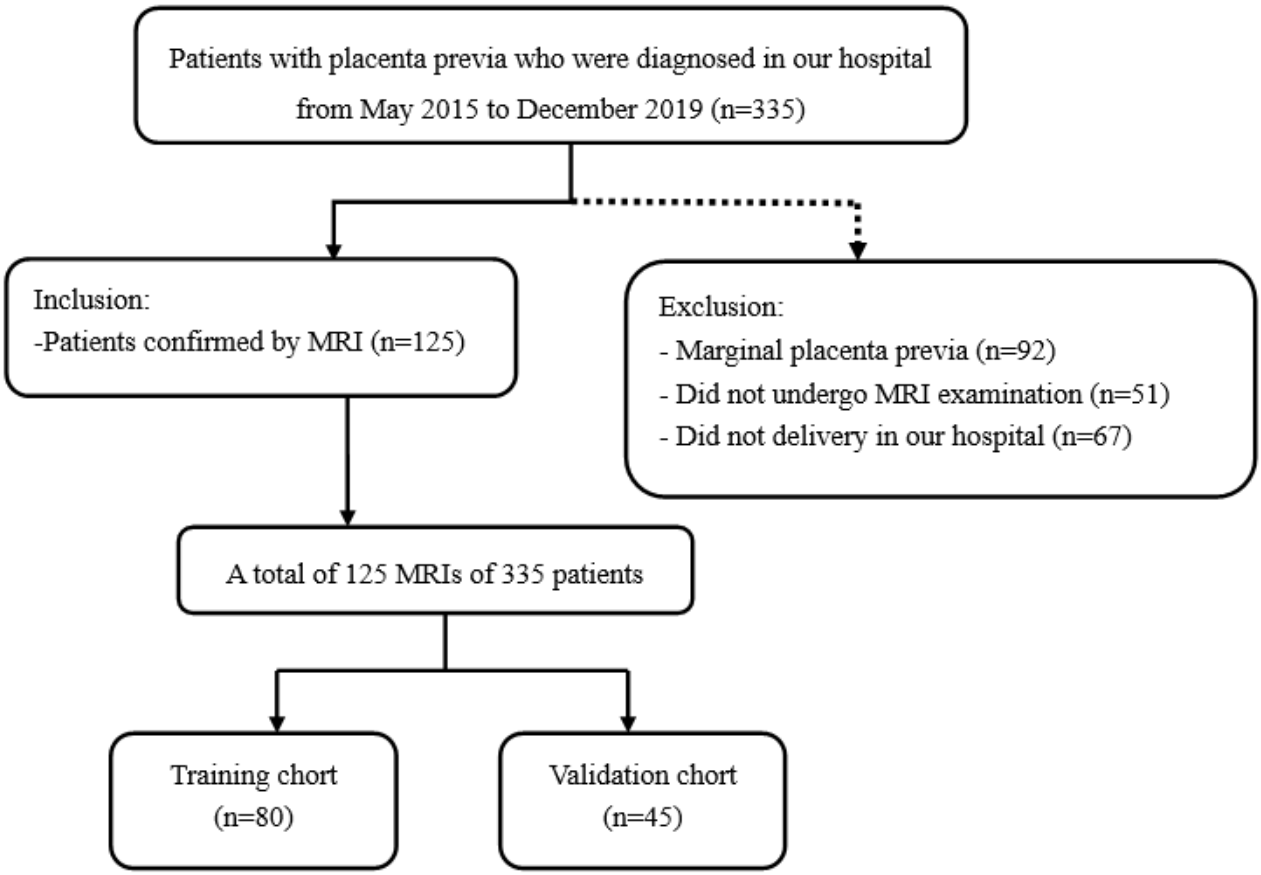

Figure 1

Flow chart of patients with placenta previa included in the study.

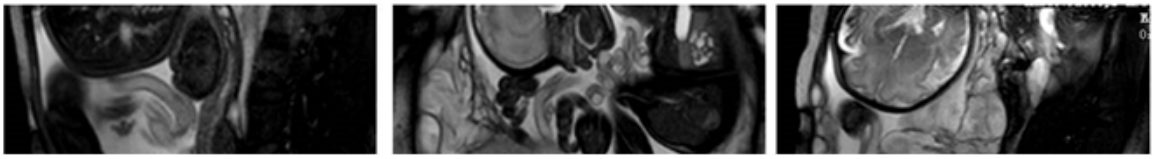

Figure 2

Different imaging characteristics of MRI in placenta previa patients.

A. Placenta thickness: The thickness of placenta is 10.31cm (Sagittal T2-weighted).

B. Bladder line: The bladder line is blurred and unclear (red arrow), invasion signs of bladder (Coronal T2-weighted).

C. Placenta pit: Dark band in placenta (red arrow), intraplacental abnormal vascularity signs (Sagittal T2-weighted).

D. Cervical blood sinus: Dark band in cervix (red arrow), enlarged and tortuous vessels signs (Sagittal T2-weighted).

E. Cervical form: The cervix is regular and complete (red arrow) (Sagittal T2-weighted).

F. Placental signals in the cervix: The signal of the cervix is consistent with that of the placenta(red arrow), sings of placenta implanted in cervix (Sagittal T2-weighted).

Figure 3

Nomogram for the prediction of IPH in patients with placenta previa. For example, a patient with complete placenta previa, MRI showed that the placenta was mainly located in the anterior wall of the uterus, placenta thickness was 7 cm, blood sinus and placental signals were visible in the cervix. The corresponding points for the four MRI features (placenta position, anterior = 26 points [black line]; placenta thickness, 7 cm =30 points [yellow line]; cervical blood sinus, Yes =

18 points [green line]; placental signals in the cervix, Yes = 22 points [blue line]) yielding a total of 96 points, which indicates the probability of IPH (IPH ≥ 2000 ml) is 0.67 [red line].

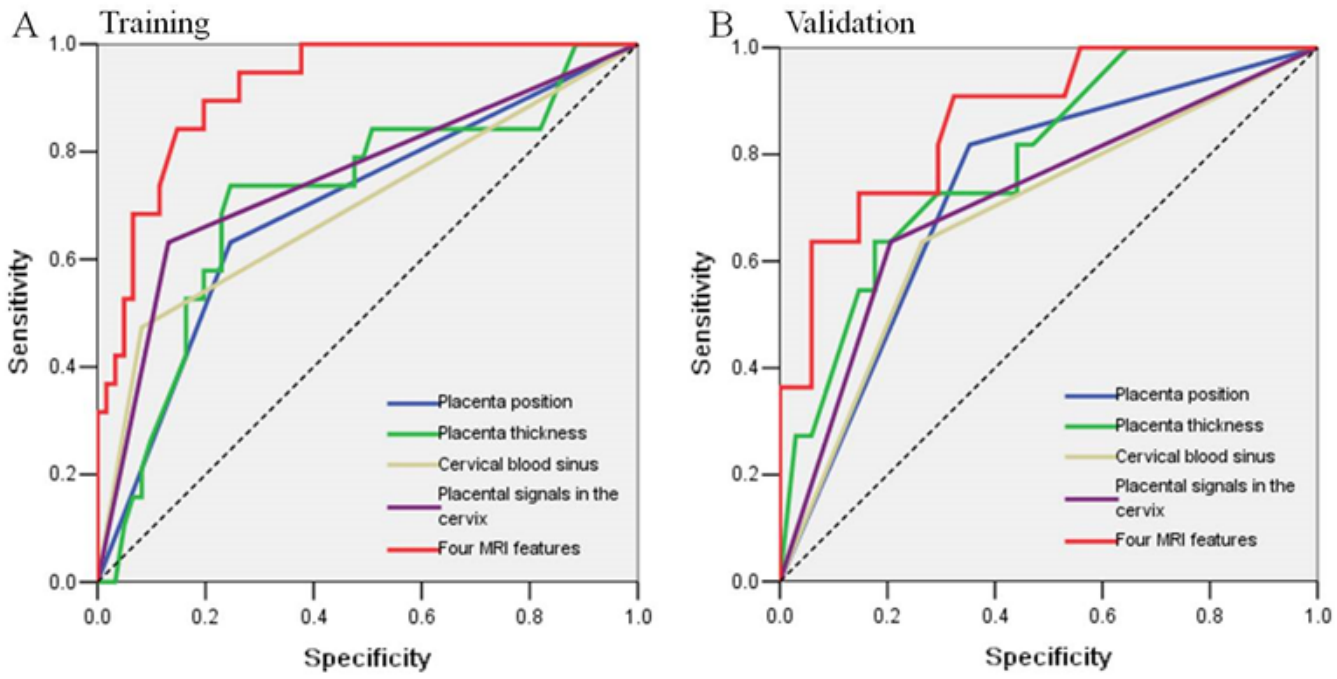

Figure 4

Receiver operating characteristics (ROC) curve for prediction of risk of IPH by different MRI features.

A. MRI model reached AUC of 0.918, with a sensitivity of 0.803 and a specificity of 0.895 by the combination of four MRI features (red line) in training set.

B. MRI model reached AUC of 0.866 , with a sensitivity of 0.778 and a specificity of 0.861 by the combination of four MRI features (red line) in validation set.

Figure 5

Calibration plots of the probability of IPH in the (A) training and (B) validation sets. The Y-axis represents the actual probability and the X-axis represents the predicted probability. The diagonal dotted line represents an ideal evaluation, while the solid line represent the performance of the nomogram. Closer fit to the diagonal dotted line indicates a better evaluation.

Figure 6

Decision curve analysis for our newly developed magnetic resonance imaging (MRI)-based model for the prediction of IPH in patients with placenta previa. On the Y-axis is the net benefit and the threshold probability is on the X-axis. The red line represents the MRI-based nomogram. The yellow line represents the assumption that all patients have IPH. The black line represents the assumption that no patients have IPH.