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Research article

The role of MRI in "estimating" intraoperative bleeding during cesarean section for placenta accreta: A prospective cohort study

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ABSTRACT

Objectives: The prenatal detection of placenta accreta spectrum (PAS) disorder is crucial for treatment strategy formulation. MRI descriptors may offer a more objective method for predicting PAS and clinical outcomes. The aim of this study is to investigate the predictive value of MRI examination for intraoperative blood loss in PAS cesarean section and elucidating the MRI descriptors that are more valuable for predicting intraoperative blood loss.

Methods: A prospective study was carried out on 164 pregnant women diagnosed with PAS. Maternal and neonatal perioperative characteristics were systematically collected. To evaluate the relationship between maternal and perioperative characteristics and intraoperative blood loss, as well as the predictive value of MRI descriptors on intraoperative blood loss, a multivariable linear regression analysis was performed.

Results: Patients were pre-grouped based on a combined ultrasound-MRI evaluation, with 108 cases (65.9 %) classified as placenta accreta, 47 cases (28.7 %) as placenta increta, and 9 cases (5.4 %) as placenta percreta. The results demonstrated that intraoperative blood loss was positively associated with partial MRI descriptors ($F = 9.751$, $df = 15$), such as placenta accreta (OR: 243.33, $p = 0.006$), cross-border blood vessels that pass through the uterine muscle layer (OR: 297.76, $p = 0.012$), interruption of hyperechoic uterus–bladder interface (bladder line) (OR: 342.59, $p = 0.011$), and subplacental hypervascularity (OR: 365.96, $p = 0.027$).

Conclusions: Preoperative MRI demonstrates promising predictive capabilities in estimating intraoperative blood loss for PAS patients. Pregnant women identified as having a high risk of intraoperative bleeding based on MRI findings should undergo closer antenatal monitoring in late pregnancy, along with more comprehensive preoperative blood preparation, to better ensure maternal and fetal safety.

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1. Introduction

Placenta accreta spectrum (PAS) is a severe complication of pregnancy, characterized by varying degrees of placental tissue invasion into the uterine wall, which may lead to life-threatening hemorrhage during childbirth and postpartum [1,2]. Over the past decade, with the overuse of cesarean section, the incidence of PAS in China has gradually increased to 1.28 % [3]. Factors such as previous cesarean sections resulting in endometrial damage and poor wound healing make it easier for chorionic villi and placental tissues to invade the uterine wall, even penetrating the serosal layer, leading to placental implantation or incomplete placental separation during delivery or cesarean section [4,5]. This condition can lead to severe hemorrhage during childbirth or cesarean section, potentially resulting in serious complications such as uterine resection or even maternal mortality [6,7].

The advancements in ultrasound imaging have enabled obstetricians to better understand the relationship between placental tissues and the uterine wall and to more accurately determine the position and degree of placental implantation [8,9]. However, ultrasound imaging has certain limitations, particularly in cases of placental attachment to the posterior uterine wall, heterogeneous placenta, and intraplacental hemorrhage [10–12]. Additionally, the accuracy of ultrasound is dependent on the proficiency of the operator. Therefore, in our hospital, pregnant women suspected of suffering PAS routinely undergo further MRI examinations at 32–34 weeks of gestation to assess the degree of placental accreta and intrauterine conditions. This allows obstetricians to better manage the perioperative period and reduce adverse pregnancy outcomes. However, the interpretation of MRI examination results is also limited by the expertise of the radiologist, and significant differences exist in the criteria used for MRI result reporting among different regions and hospitals [1,13,14].

Therefore, we prospectively collected MRI and perinatal data from 277 pregnant women suspected of suffering PAS. The aim of this study is to investigate the perinatal outcomes of pregnant women with different types of PAS and the predictive value of MRI examination for intraoperative blood loss in severe PAS cesarean section. This is also aimed at elucidating the imaging markers of MRI that are more valuable for predicting intraoperative blood loss, providing a reference for the wider application of MRI examination in placenta accreta spectrum.

2. Materials and methods

2.1. Study design and participants

This study was conducted in Chengdu, aimed at exploring an adequate way of determining the disorder for PAS to make early diagnosis. The study enrolled all women suspected of suffering PAS based on mid-pregnancy ultrasound between January 2020 and December 2023. Ethical approval for this study was obtained from the Ethics Committee of Chengdu Women's and Children's Center Hospital (Ethics DOI: 201830). All participants provided informed consent, either in written or verbal form. Based on previous studies of combined ultrasound MRI evaluation in PAS [15], and incorporating a 10 % increase to account for potential dropout, the required sample size was calculated to be 248 cases. Due to the high incidence of adverse outcomes, twin pregnancies were excluded from the study. Infants with severe malformations or genetic diseases were also excluded from the study. MRI is our intervention for patients suspected of PAS by ultrasound. This study performed MRI examination with the consent of the patients, to realize the correlation analysis of preoperative MRI and perioperative data. MRI examination was performed on pregnant mothers suspected of PAS by ultrasound at 32–34 weeks of gestation using magnetic resonance imaging (MRI, Ingenia Elition 3.0T, Netherlands). Patients were pre-grouped based on MRI and ultrasound examination results into Placenta Accreta, Placenta Increta, and Placenta Percreta groups.

2.2. Data collection

During the first antenatal visit at 12–14 weeks of gestation, sociodemographic data of the pregnant women (including age, weight, height, job, gravidity, etc.), medical history, and lifestyle behaviors (alcohol consumption and smoking), were extracted from medical records. And the data of pregnancy complications, as well as maternal and newborn's outcomes, were gathered from hospital records, including premature rupture of membranes (before 37 weeks of gestation), gestational age, newborn's gender, and intraoperative blood loss (assessed through collection bags), birth weight of newborns, neonatal asphyxia (5-/10-min Apgar scores), among other variables. Blood loss exceeding 1000 mL during cesarean section is defined as major hemorrhage.

2.3. The cesarean delivery indications for pregnant women suffering PAS

Previous studies have suggested that delivery before term in pregnant women suffering PAS may reduce the risk of adverse outcomes [16]. Hence, we recommend that pregnant women suffering PAS and no antepartum hemorrhage undergo cesarean section at 36 weeks of gestation, while those with PAS and recurrent mild antepartum hemorrhage undergo cesarean section at 34 weeks of pregnancy in our institution. In case of sudden heavy vaginal bleeding (>100 mL) or if a pregnant woman reports a significant decrease in fetal movements, along with umbilical cord blood flow or abnormal antenatal fetal monitoring, an emergency cesarean section will be performed.

2.4. The surgical procedure of pregnant women suffering PAS

Preoperative: 1) Combined transvaginal and transabdominal ultrasound placental scoring, placental MRI, (Supplementary Table 1), multidisciplinary discussion, blood preparation; 2) Preoperative bedside ultrasound examination by the primary surgeon to confirm placental location, fetal position, assess the uterine and abdominal wall incision sites, and make the necessary markings; 3) For balloon occlusion, perform cervical vein catheterization and radial artery puncture to monitor invasive blood pressure.

Intraoperatively: 1) For patients where the placenta can be avoided, attempt to place the uterine incision above the upper margin of the placenta. If the placenta extensively covers the anterior uterine wall, enter the uterine cavity through the thinnest portion of the placenta, and a double incision would be performed at the uterus if necessary; 2) Following fetal delivery, the interventional physician promptly occludes the balloon, if indicated. The first assistant would take the uterus out from the abdominal cavity, securely holding the lower segment with both hands. Meanwhile, the second assistant performs ligation of the lower uterine segment using a urinary catheter. Subsequently, the primary surgeon employs an oval clamp to secure the edge of the uterine incision, displaces the bladder downward, administers oxytocin into the uterine muscle layer, and allows time for the placenta to detach spontaneously. If spontaneous detachment does not occur, bluntly separate the placenta using vascular forceps and fingers, taking care to avoid damaging the blood sinuses. Depending on the bleeding, perform the following procedures sequentially: ligation of the uterine artery ascending branch, anterior uterine wall weaving suture, posterior uterine wall dam-like suture, B-Lynch suture, uterine cavity balloon inflation, and closure of the uterine incision.

Postoperatively, for pregnant women suffering PAS with bleeding exceeding 2000 mL or those undergoing uterine hysterectomy are transferred to the Intensive Care Unit (ICU). Patients in the ICU are managed jointly by ICU physicians and obstetricians, and they are transferred to the obstetrics department once their condition stabilizes.

2.5. MRI data

MRI examination was performed on pregnant mothers suspected of PAS by ultrasound at 32–34 weeks of gestation using MRI. The examination aimed to assess the relationship between placental tissue and the uterine muscle layer. Horizontal parameters were set as follows: Turbo Spin Echo/Extended (TSE/E), fast echo train (fet), Single-Shot Turbo Spin Echo with Sensitivity Encoding (SSh-TSE SENSE), Scan Duration (ScDur, 1:30m), Repetition Time (TR, 15000), Echo Time (TE, 121), Field of View (FOV, 450), Slice Thickness/Gap (THK, 4.5/1.9), and Gradient Coils (GC, 2D). Vertical parameters were set as follows: 3 T (3T), TSE/E, fet, SSh-TSE SENSE, ScDur (1:15m), TR (15000), TE (94), FOV (400), THK (4.5/1.7), and GC (2D).

Some special MRI descriptors are defined as follows: Myometrial thinning (the thickness of the thinnest part of the myometrium is

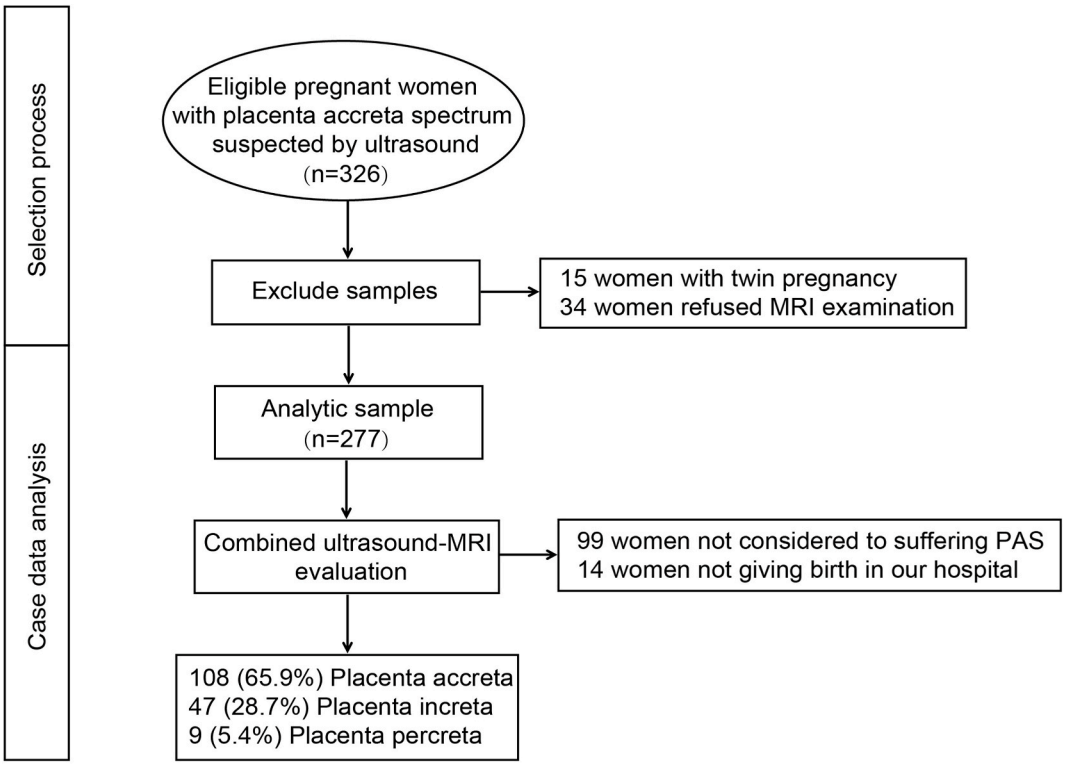

Fig. 1. The selection process for this study.

less than 1 mm), Subplacental hypervascularity (the increase in blood vessels in the gap between the placenta and the uterus and in the part of the uterus covered by the placenta).

2.6. Statistical methods

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., USA). Categorical data were evaluated using chi-square tests or Fisher's exact tests, with results reported as frequencies and percentages. Means and standard deviations were used to describe continuous variables. Comparisons between groups were performed using Student's t-test and the least significant difference (LSD) test to determine statistical significance. Multiple linear regression analysis was utilized to examine the correlation between maternal and perioperative characteristics and intraoperative blood loss. Covariates were selected based on different variables in univariate analysis and factors reported to influence the dependent variable in previous studies. All statistical tests were conducted using a two-tailed approach, with significance defined as a p-value of less than 0.05.

3. Results

Fig. 1 shows the participant selection process. Initially, 277 pregnant women at 32–34 weeks of gestation suspected of having PAS were recruited and underwent MRI examination. After excluding patients with placental implantation excluded by MRI or who did not meet the inclusion criteria, the final analysis included 164 patients. The recruited mothers had a mean age of 31.78 ± 4.69 years, with an average ultrasound placental score of 6.25 ± 1.58 and a mean gestational age of 36.09 ± 1.82 weeks. The mean birthweight of the newborns was 2755.97 ± 512.38 g, with 133 cases (81.1 %) being preterm births. The mean intraoperative blood loss was 895.48 ± 656.26 mL. Patients were pre-grouped based on a combined ultrasound-MRI evaluation, with 108 cases (65.9 %) classified as placenta accreta, 47 cases (28.7 %) as placenta increta, and 9 cases (5.4 %) as placenta percreta, finally included for analysis in Table 1.

In the placenta increta and percreta groups, the mean intraoperative blood loss during cesarean section was as high as 1179 mL, with a major hemorrhage rate of 62.5 % and a uterine resection rate of 8.9 %. The incidence of neonatal asphyxia reached 16.1 %. However, there were no reported cases of maternal or neonatal mortality (Table 1).

The univariate analysis revealed a statistically significant difference in mean intraoperative blood loss among the three groups (Accreta vs Increta vs Percreta: 748.01 vs 1088.12 vs 1659.83 mL, $p < 0.001$) (Table 2). Multiple linear regression analysis was used to further clarify the influencing factors of intraoperative bleeding volume. After adjusting for maternal age, pre-pregnancy BMI, incision direction, anemia, and gestational age, the results showed significant correlations between ultrasound placental score and intraoperative blood loss, preoperative balloon occlusion, PAS type, emergency cesarean section, and duration of surgery. The predictor in this analysis is intraoperative bleeding, and the predicted variables are PAS type, emergency cesarean section, preoperative balloon occlusion, placental score, and duration of surgery. Intraoperative blood loss was positively correlated with PAS type, duration of surgery, emergency cesarean section, and placental score in Fig. 2A. For each one-point increase in placental score, blood loss

Table 1
Description of the maternal characteristics by PAS type based on combined ultrasound-MRI evaluation (N = 164).

Variables	Total	Placenta Accreta	Placenta Increta	Placenta Percreta	p-value
Mothers	N = 164	N = 108	N = 47	N = 9	
Age (year)	31.78 ± 4.69	31.73 ± 4.36	31.71 ± 4.54	32.78 ± 5.62	0.183[a]
Pre-pregnancy BMI (kg/m2)	23.55 ± 3.75	23.32 ± 3.21	24.02 ± 3.39	23.92 ± 3.35	0.409[a]
Mode of conception (ART)	3(3.8 %)	1(0.9 %)	2(4.3 %)	0(0 %)	0.172[d]
Gestational weight gain (kg)	12.32 ± 3.02	12.46 ± 2.89	12.23 ± 3.37	11.26 ± 2.62	<0.001[a]
Gestational age (week)	36.09 ± 1.82	36.21 ± 1.30	36.02 ± 1.49	35.00 ± 1.91	<0.001[a]
Premature delivery	133(81.1 %)	83(76.9 %)	41(87.2 %)	9(100.0 %)	<0.001[c]
Smoking	10(6.1 %)	6(5.6 %)	3(6.4 %)	1(11.1 %)	0.167[d]
Pregnancy-induced illness					
GDM	41(25.0 %)	26(24.1 %)	13(27.7 %)	2(22.2 %)	0.592[d]
GHD	9(5.5 %)	4(3.7 %)	2(4.3 %)	3(33.3 %)	0.034[d]
ICP	8(4.9 %)	6(5.6 %)	2(4.3 %)	0(0 %)	0.152[d]
FGR	6(3.7 %)	4(3.7 %)	1(2.1 %)	1(11.1 %)	0.286[d]
Gravidity	3.60 ± 1.96	3.52 ± 1.91	3.66 ± 1.82	4.22 ± 1.16	0.126[b]
Parity	1.88 ± 0.67	1.83 ± 0.61	1.97 ± 0.53	1.95 ± 0.37	0.233[b]
Number of prior cesarean sections	1.41 ± 0.60	1.31 ± 0.56	1.53 ± 0.65	1.94 ± 0.32	0.028[b]
Prenatal bleeding rate	79(48.2 %)	53(49.1 %)	21(44.7 %)	5(55.6 %)	0.539[c]
Times of prenatal bleeding	1.14 ± 1.64	1.21 ± 1.59	1.02 ± 1.34	0.94 ± 1.21	0.521[b]
Number of prior D&C abortions	1.47 ± 1.53	1.44 ± 1.46	1.56 ± 1.49	1.39 ± 1.03	0.212[b]
Anemia	45(27.4 %)	31(28.7 %)	11(23.4 %)	3(33.3 %)	0.759[d]

PAS placenta accreta spectrum, ART Assisted reproductive technology, BMI body mass index, GDM gestational diabetes, GHD gestational hypertension disorder, ICP intrahepatic cholestasis of pregnancy, FGR fetal growth restriction.

[a] Average and standard deviation. One-way Analysis of Variance.

[b] Average and standard deviation. Kruskal-Wallis Test.

[c] Number (percentage). Chi-squared Test.

[d] Number (percentage). Fisher Exact Test.

Table 2
Description of the perinatal characteristics by PAS type based on MRI and Ultrasound examination (N = 164).

Variables	Placenta Accreta	Placenta Increta	Placenta Percreta	p-value
Mothers	N = 108	N = 47	N = 9	
Emergency cesarean section	15(13.9 %)	5(10.6 %)	1(11.1 %)	0.865[d]
Placental score	5.53 ± 0.98	7.15 ± 1.13	10.21 ± 1.79	<0.001[a]
Prophylactic balloon occlusion	13(12.0 %)	25(53.2 %)	8(88.9 %)	<0.001[c]
Duration of surgery(min)	62.88 ± 53.56	85.97 ± 75.22	107.63 ± 87.63	<0.001[a]
Intraoperative bleeding	748.01 ± 82.32	1088.12 ± 109.21	1659.83 ± 273.35	<0.001[a]
Hemoglobin difference (g/L)	12.61 ± 1.57	21.81 ± 2.62	32.13 ± 2.44	<0.001[a]
Caesarean hysterectomy	1(0.9 %)	3(6.4 %)	2(22.2 %)	0.005[d]
Death	0(0 %)	0(0 %)	0(0 %)	–
Infants				
Birthweight (g)	2810.62 ± 418.37	2683.97 ± 379.50	2477.78 ± 388.15	<0.001[a]
Height (cm)	48.31 ± 2.78	47.55 ± 2.05	46.06 ± 3.13	0.038[b]
Neonatal asphyxia	4(3.7 %)	6(12.8 %)	3(33.3 %)	0.015[d]

PAS placenta accreta spectrum.
[a] Average and standard deviation. One-way Analysis of Variance.
[b] Average and standard deviation. Kruskal-Wallis Test.
[c] Number (percentage). Chi-squared Test.
[d] Number (percentage). Fisher Exact Test.

increased by approximately 137 mL (Adjusted OR: 136.94; p = 0.017); with each minute increase in the duration of surgery, blood loss increased by approximately 18 mL (Adjusted OR: 17.87; p < 0.001). Preoperative prophylactic balloon occlusion significantly reduced blood loss by 202 mL (Adjusted OR: 202.05; p = 0.024) (Fig. 2A). Additionally, when an emergency cesarean section occurred, intraoperative blood loss significantly increased by 221 mL (Adjusted OR: 221.79; p = 0.025), and with more severe PAS types, blood loss increased by 276 mL (Adjusted OR: 276.03; p = 0.003) (Fig. 2B).

Further analysis was conducted on the interactions between the uterus and placenta as indicated by MRI. The top five indicators in terms of prevalence were thinning of the uterine muscle layer (43.7 %), placental coverage of the cesarean scar (39.4 %), placenta accreta (33.9 %), anterior placental attachment (32.5 %), and low echogenicity in the posterior uterine space (30.0 %). By comparing the positivity of MRI-indicated indicators with intraoperative blood loss, the predictive value of MRI data for intraoperative bleeding was further explored. The results of multiple linear regression analysis showed that MRI indications such as placenta covering the cesarean scar, placenta accreta, position of placenta attachment(anterior wall), cervical canal shortening <2.5(cm), interruption of the uterine muscle layer, cross-border blood vessels that pass through the uterine muscle layer, focal exophytic mass and/or placental bulge, myometrial thinning, interruption of hyperechoic uterus–bladder interface (bladder line), and subplacental hypervascularity were significantly associated with increased intraoperative blood loss (p < 0.05) (Table 3).

Further incorporating the aforementioned factors into multiple linear regression analysis, the results further demonstrated that intraoperative blood loss was positively associated with placenta accreta (Adjusted OR: 243.33, p = 0.006), cross-border blood vessels that pass through the uterine muscle layer (Adjusted OR: 297.76, p = 0.012), interruption of hyperechoic uterus–bladder interface (bladder line) (Adjusted OR: 342.59, p = 0.011), and subplacental hypervascularity (Adjusted OR: 365.96, p = 0.027. However, intraoperative blood loss was not associated with Placenta covering the cesarean scar, position of placenta attachment (anterior wall), cervical canal shortening <2.5(cm), interruption of the uterine muscle layer, placenta covering the cervical inner os, focal exophytic

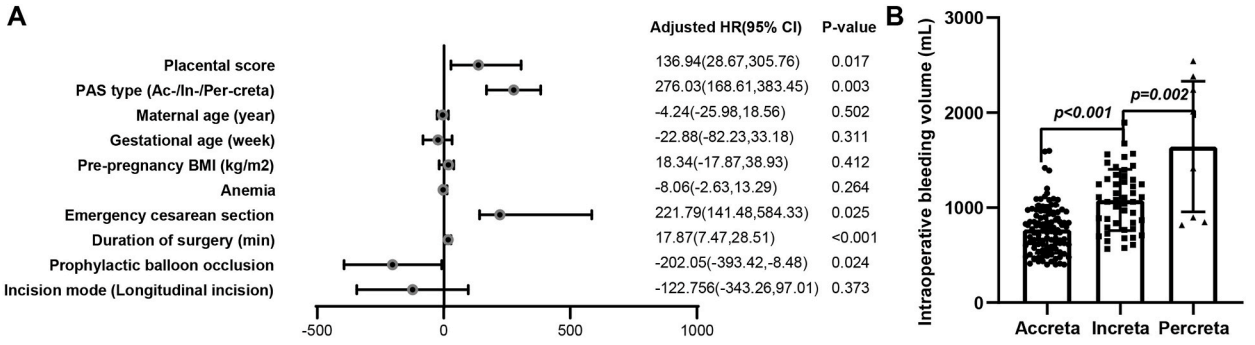

Fig. 2. Association between perioperative characteristics and intraoperative bleeding volume by multiple linear regression analysis. A) After adjusting for maternal age, pre-pregnancy BMI, gestational age, anemia, and incision direction, the results showed a significant correlation between intraoperative blood loss and ultrasound placental score, duration of surgery, preoperative balloon occlusion, emergency cesarean section, and PAS type; B) The amount of intraoperative bleeding was significantly different among placenta accreta, increta, and percreta groups (p < 0.001 Accreta vs Increta; p = 0.002 Increta vs Percreta).

Table 3
Description of the volume of intraoperative bleeding by MRI data characteristics (N = 277).

Variables	Total N = 277	Volume of intraoperative bleeding		
		Yes	No	p-value[a]
Placenta covering the cesarean scar	109(39.4 %)	1152.29 ± 865.02	698.51 ± 412.18	<0.001
Placenta accreta	94(33.9 %)	1184.04 ± 842.97	719.40 ± 487.78	<0.001
Position of placenta attachment(Anterior wall)	90(32.5 %)	1098.33 ± 838.42	770.59 ± 537.36	<0.001
Cervical canal shortening <2.5(cm)	18(6.5 %)	1444.44 ± 1169.83	837.64 ± 601.47	0.017
Interruption of the uterine muscle layer	19(6.9 %)	1810.53 ± 1357.24	808.33 ± 528.80	0.010
Placenta covering the cervical inner os	80(28.9 %)	895.69 ± 702.43	831.25 ± 572.05	0.467[a]
Cross-border blood vessels that pass through the uterine muscle layer	34(12.3 %)	1508.82 ± 1197.06	788.68 ± 498.10	<0.001
Hypoechoic retroplacental space ("clear zone")	83(30.0 %)	993.98 ± 817.25	827.06 ± 586.6	0.256
Focal exophytic mass and/or placental bulge	52(18.8 %)	1313.46 ± 953.02	776.22 ± 535.71	<0.001
Myometrial thinning	121(43.7 %)	1081.82 ± 874.64	718.27 ± 376.66	<0.001
Interruption of hyperechoic uterus–bladder interface (bladder line)	8(2.9 %)	2287.50 ± 1835.71	835.13 ± 555.91	0.022
Subplacental hypervascularity	15(5.4 %)	1496.67 ± 1439.06	841.6 ± 579.72	0.009

[a] Average and standard deviation. Student's t-test.

mass and/or placental bulge, and myometrial thinning (Table 4).

4. Discussion

In this prospective preliminary study, we investigated MRI data and perinatal outcomes of 277 pregnant women suspected of having PAS. We further analyzed the perinatal outcomes of pregnant women with different types of PAS and the predictive value of MRI examination for intraoperative blood loss in severe placenta accreta spectrum cesarean deliveries. The aim was also to elucidate the imaging parameters more valuable for predicting intraoperative blood loss and to provide a reference for the broader application of MRI examination in PAS disorders.

PAS is a clinical diagnosis characterized by significant variability in diagnostic criteria. According to the most stringent classification guidelines from the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG), PAS cannot be definitively confirmed without performing a hysterectomy [17,18]. However, in our study, only 6 patients (3.7 %) underwent hysterectomy, leading us to favor a more comprehensive preoperative assessment of patients. In our institution, placental scoring via ultrasound and a combined ultrasound-MRI evaluation are used for preoperative classification of PAS in patients. The preoperative ultrasound diagnosis of PAS achieves an accuracy rate of 83.3–89.6 % [19,20], rendering it relatively reliable for diagnosing PAS in patients.

The application of ultrasound in PAS has been validated in previous studies [21,22]. However, ultrasound imaging has certain limitations in cases where the placenta is attached to the posterior uterine wall, heterogeneous placenta, or placental hemorrhage, and its accuracy is limited by the operator's proficiency [10,23]. In our study, 34.9 % of intraoperative blood loss could be explained by MRI data, which is a relatively high proportion. The primary risk factor for PAS is uncontrolled massive bleeding, which is one of the most serious pregnancy complications. Based on MRI data, appropriate termination of pregnancy timing can be calculated based on the maternal intrauterine condition, gestational age, fetal status, etc. This is consistent with previous studies [15], for pregnant women with PAS, routine MRI in late pregnancy allows for early assessment of bleeding risk and intraoperative blood loss. This study confirms that preoperative abdominal aortic balloon occlusion effectively reduces intraoperative bleeding during cesarean sections for PAS, consistent with findings from previous research [17]. For high-risk PAS patients, adequate blood preparation should be performed preoperatively, and uterine blood volume should be reduced through abdominal aortic balloon occlusion. Therefore, MRI examination can serve as a beneficial supplementary method for pregnant women with PAS before cesarean section. Preoperative MRI assessment of the placenta and intrauterine condition provides significant benefits for pregnant women with PAS, facilitating improved preoperative planning and postoperative recovery.

Table 4
Association between MRI data characteristics and volume of intraoperative bleeding by multiple linear regression analysis (N = 277).

Variables	Adjusted OR	95 % CI	P-value	VIF
$R^2 = 0.349/F = 9.751/df = 15$				
Placenta covering the cesarean scar	151.34	(-9.66,312.35)	0.065	1.260
Placenta accreta	243.33	(30.85,455.81)	0.006	1.055
Position of placenta attachment(Anterior wall)	50.29	(-28.03,128.63)	0.207	1.488
Cervical canal shortening (<2.5 cm)	171.63	(-131.80,475.06)	0.324	1.351
Interruption of the uterine muscle layer	292.14	(-23.02,607.32)	0.069	1.125
Placenta covering the cervical inner os	−80.66	(-229.16,67.83)	0.286	1.571
Cross-border blood vessels that pass through the uterine muscle layer	297.76	(67.00,528.52)	0.012	1.169
Focal exophytic mass and/or placental bulge	85.07	(-123.89,294.04)	0.423	1.255
Myometrial thinning (<0.1 cm)	140.93	(-2.37,284.23)	0.145	1.071
Interruption of hyperechoic uterus–bladder interface (bladder line)	342.59	(106.06,579.12)	0.011	1.458
Subplacental hypervascularity	365.96	(66.83,665.09)	0.027	1.573

However, the interpretation of MRI examination results is also limited by the expertise of the radiologist, and significant differences exist in the criteria used for MRI result reporting among different regions and hospitals [24,25]. Based on our findings, we utilized regression analysis to identify MRI indicators that are more valuable in predicting intraoperative blood loss, providing a reference basis for the broader application of MRI examinations in PAS. Pre-grouping is generally performed after MRI examination between 32 and 34 weeks of pregnancy based on combined ultrasound-MRI evaluation because, during early and mid-pregnancy, the relative position of the placenta and uterus can change due to uterine enlargement. After 32 weeks, the relationship between the placenta and uterus stabilizes [26], allowing MRI to further clarify their relationship. Additionally, due to the possibility of PAS patients experiencing bleeding before the due date and undergoing emergency surgery, the evaluation should not be conducted too late.

For PAS patients scheduled for cesarean section, our institution has established a multidisciplinary team to ensure the availability of blood products, surgical personnel, and necessary equipment. This team includes experts from the blood bank, obstetrics, urology, anesthesia, and neonatology. Comprehensive blood preparation enables obstetricians to have a greater opportunity and confidence in uterine preservation. Furthermore, in previous studies, the intraoperative hysterectomy rate for pregnant women suffering PAS was up to 16.3–25.0 % [27], with an average intraoperative bleeding volume greater than 2000 mL [28], the intraoperative blood loss and uterine resection rate among PAS patients in our institution are significantly lower compared to previous studies [29,30]. A timely and detailed patient monitoring approach could be responsible for this success. Therefore, we recommend transferring complex cases such as PAS to specialized hospitals to ensure the safety of both mothers and infants.

Our study possesses several strengths, including standardized surgical procedures and a large sample size. Participants were selected based on stringent inclusion and exclusion criteria, ensuring high-quality data. All cesarean sections were performed following a standardized surgical protocol, ensuring consistency in intraoperative data collection. Additionally, comprehensive data on maternal and perioperative outcomes were analyzed, which strengthened the study's design and robustness. The low natural incidence of PAS presented challenges in recruiting and following up with a large cohort of pregnant women with PAS within a single hospital over a four-year period. Our hospital is one of the largest and most specialized maternity hospital in Southwest China, allowing us to examine these important conditions using a large sample size.

This preliminary study enhances our understanding of the predictive role of MRI in estimating intraoperative blood loss during cesarean sections for PAS pregnancies. However, it has several limitations. Firstly, the sample size is relatively modest compared to studies on more common pregnancy disorders. Secondly, this study is a single-center investigation. Large-scale studies involving a greater number of patients with various types of PAS across multiple centers are needed to provide clearer insights into the role of MRI in predicting intraoperative blood loss and to validate these findings further.

5. Conclusions

Preoperative MRI demonstrates good predictive capabilities in estimating intraoperative blood loss for PAS patients, with 34.9 % of intraoperative blood loss in PAS pregnancies being explainable by preoperative MRI results. The MRI indicators of placenta accreta, cross-border blood vessels that pass through the uterine muscle layer, interruption of hyperechoic uterus–bladder interface (bladder line), and subplacental hypervascularity are independent risk factors for increased intraoperative blood loss. For pregnant women identified by MRI as having a high risk of intraoperative bleeding, closer antenatal monitoring in late pregnancy and more comprehensive preoperative blood preparation are recommended to better ensure maternal and fetal safety.

Data availability statement

Data are available upon reasonable request to the corresponding author.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36480.

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