

A LASSO-Based Ultrasound–MRI Scoring Model for Predicting Severe Maternal Outcomes in Placenta Accreta Spectrum

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Research Article

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Abstract

Objective: To evaluate the predictive value of a weighted scoring model based on LASSO logistic regression integrating ultrasound and magnetic resonance imaging (MRI) for severe adverse maternal outcomes (SAMO) in patients with placenta accreta spectrum (PAS). SAMO was defined as hysterectomy and/or postpartum hemorrhage ≥ 1500 mL within 24 hours.

Methods: A total of 133 patients with PAS who delivered at our hospital between January 2020 and December 2022 were retrospectively enrolled. Patients were divided into the SAMO group ($n=49$) and the non-SAMO group ($n=84$). Twenty-one prenatal ultrasound and MRI imaging features were evaluated. LASSO logistic regression was used to identify independent predictors and to construct a weighted scoring model. Model performance was assessed using the receiver operating characteristic (ROC) curve. Clinical utility was evaluated using decision curve analysis (DCA) to quantify net benefit across different risk thresholds.

Results: LASSO logistic regression initially selected 11 imaging features with non-zero coefficients from the 21 candidate variables. After excluding three features with negligible coefficients (assigned zero weight in the simplified scoring system), eight predictors were retained to construct an 11-point weighted scoring model: anterior placental location, placenta previa, placental thickness ≥ 5 cm, placental lacunae, cervical length ≤ 2.5 cm, lower uterine segment myometrial thickness ≤ 1 mm, intraplacental T2-weighted (T2WI) low-signal bands, and the “tenting sign.” These predictors were assigned weights of 1–2 points to construct an 11-point scoring system. The model achieved an AUC of 0.879 (95% CI: 0.812–0.945) with a sensitivity of 75.51% and a specificity of 88.10% at the optimal cutoff of 7 points. Patients with a score ≥ 7 had a significantly higher risk of SAMO (OR=22.82, 95% CI: 9.03–57.68). DCA demonstrated a positive net clinical benefit across a wide range of threshold probabilities (approximately 0.05–0.85), substantially outperforming both the “treat-all” and “treat-none” strategies.

Conclusion: This internally validated ultrasound–MRI combined scoring system provides a clinically practical tool for early risk stratification of severe maternal outcomes in patients with PAS. The model demonstrates robust predictive performance and clear clinical utility. Future external validation studies are warranted to confirm its generalizability across diverse healthcare settings.

1 Introduction

Placenta accreta spectrum (PAS) is a serious obstetric complication characterized by abnormal adherence, invasion, or penetration of placental villi into or through the uterine myometrium^[1]. This pathological process prevents normal placental separation after delivery and represents a major cause of severe postpartum hemorrhage, peripartum hysterectomy, and maternal mortality^[1–2]. With the global rise in cesarean section rates, the incidence of PAS increased from 0.05% to 0.2% between 1928 and 2002^[3]. In China, the burden of PAS is particularly prominent due to historically high cesarean section rates, further influenced by the implementation of the “two-child” and “three-child” policies^[4]. Despite

advancements in multidisciplinary management, accurate prenatal prediction of PAS remains challenging.

Current diagnostic strategies primarily rely on ultrasound (US) as the first-line imaging modality, with magnetic resonance imaging (MRI) serving as an adjunct in complex or inconclusive cases^[5–7]. Several studies have attempted to integrate US and MRI features to develop scoring systems for the prenatal diagnosis and risk stratification of PAS^[8–14]. However, most existing scoring systems focus on diagnosing PAS or assessing the depth of placental invasion, with few models specifically designed to predict severe adverse maternal outcomes (SAMO), such as hysterectomy and massive hemorrhage^[8–13]. Traditional risk assessment based solely on clinical factors, including prior cesarean deliveries, placenta previa, and maternal age, has demonstrated limited predictive value^[15]. In contrast, multimodal imaging approaches that leverage the complementary strengths of US and MRI have shown superior predictive capability^[8–13]. The integration of these imaging modalities addresses a fundamental clinical need: shifting from diagnostic accuracy toward outcome prediction to enable precision medicine approaches in PAS management^[16].

LASSO (Least Absolute Shrinkage and Selection Operator) regression is well suited for high-dimensional data, as it employs L1 regularization to perform variable selection and prevent overfitting. This study utilized LASSO regression to identify key ultrasound and MRI predictors and to construct a weighted scoring model for SAMO in patients with PAS. The model aims to provide a more precise risk stratification tool to guide individualized management and optimize resource allocation.

Against this background, we developed an early warning scoring system based on combined ultrasound and MRI features using LASSO logistic regression to predict SAMO in patients with PAS. This approach seeks to bridge the gap between diagnostic accuracy and clinical utility by providing actionable risk stratification to support individualized clinical decision-making.

2 Materials and Methods

2.1 Study Population This retrospective cohort study included 133 patients with PAS who delivered at Chengdu Women's and Children's Central Hospital between January 1, 2020, and December 31, 2022. The inclusion criteria were as follows: (1) cesarean delivery; (2) intraoperative or pathological confirmation of PAS; (3) availability of complete prenatal ultrasound and MRI examinations; and (4) complete clinical data. Patients with severe postpartum hemorrhage caused by conditions other than PAS (e.g., coagulation disorders) were excluded. Patients were categorized into the SAMO group (n=49) and the non-SAMO group (n=84) according to the occurrence of hysterectomy and/or postpartum hemorrhage ≥ 1500 mL (Figure 1).

This study was approved by the Institutional Review Board (Ethics Committee) of Chengdu Women's and Children's Central Hospital (Approval No.: Scientific Research Ethics B2018(8)). Written informed consent was not required because of the retrospective nature of the review.

2.2 Methods

2.2.1 Definitions (1) *Placenta accreta spectrum (PAS)* was diagnosed by postoperative pathological examination (showing chorionic villi directly attached to or penetrating the uterine myometrium with decidual deficiency at the placental-uterine interface) or intraoperative findings (a bluish-purple area at the placental implantation site, retained placenta, difficulty with manual removal, and profuse bleeding from the placental bed)^[17]. (2) *Grade II PPH* was defined as blood loss ≥ 1500 mL within 24 hours after delivery. This threshold is based on the international standard where blood loss of 1000–1500 mL (approximately 25% of total blood volume) is associated with symptoms of hemorrhagic shock^[18]. (3) *Severe adverse maternal outcome (SAMO)* was defined as the occurrence of hysterectomy and/or grade II PPH.

2.2.2 Ultrasound Examination All ultrasonographic examinations were performed by experienced sonographers (≥ 5 years of experience in PAS diagnosis) using a GE Voluson E10 or E8 ultrasound system equipped with 5–9 MHz transabdominal and 5–8 MHz transvaginal probes. Examinations were conducted between 28 and 34 weeks of gestation, with a primary focus on evaluating placental attachment at the lower uterine segment. All ultrasound reports were independently reviewed by three senior sonographers (associate chief physicians or above); any discrepancies in interpretation were adjudicated by a fourth chief physician to reach a final consensus. The assessment included 11 ultrasonographic features: placental location (anterior or posterior), placental type (low-lying or previa), myometrial thickness at the placental attachment site, placental thickness, integrity of the retroplacental hypoechoic zone, integrity of the bladder–uterine interface (“bladder line”), placental lacunae, subplacental hypervascularity, bridging vessels, cervical sinuses, and cervical morphology^[19–21].

2.2.3 MRI Image Analysis MRI was performed within one week after the ultrasound examination using a Siemens MAGNETOM Skyra 3.0T MRI system. The scanning protocol included T2-weighted imaging (T2WI) in axial, sagittal, and coronal planes, and T1-weighted imaging (T1WI) in the axial plane. All MRI images were independently reviewed by two associate chief radiologists, each with more than 5 years of experience in obstetric and gynecologic imaging. In cases of diagnostic disagreement, a third chief radiologist was consulted to reach a final consensus. The assessment included 10 MRI features: cervical length, myometrial thickness in the lower uterine segment, integrity of the T2WI hypointense line, intraplacental T2WI dark bands, morphology of the lower uterine segment, relationship between the placenta and uterine contour, the “tenting sign” relationship between the placenta and the cervical canal, placental bed vascularity, and bridging vessels^[20].

2.2.4 Blood Loss Measurement and Pathological Confirmation Postpartum blood loss was measured using a combination of volumetric and gravimetric (weight-based) methods, with results independently verified by two healthcare professionals^[18]. All delivered placentas and uterine specimens underwent standardized pathological examination according to established diagnostic criteria for PAS^[17].

2.3 Statistical Analysis

Statistical analyses were performed using SPSS (version 22.0) and Python (version 3.9). Continuous variables were expressed as mean $\pm$ standard deviation (SD), and categorical variables were presented as frequencies and percentages. Differences in demographic characteristics, pregnancy complications, and placental invasion status between the two groups were compared using the independent-samples t-test for continuous variables and the chi-square test or Fisher's exact test for categorical variables.

LASSO-penalized logistic regression was applied to select independent predictors of SAMO from 21 candidate imaging features. The regularization parameter (λ) was optimized using 5-fold cross-validation with 1000 iterations, and the value that maximized the area under the receiver operating characteristic curve (AUC) was selected. The LASSO method applies an L1 penalty to regression coefficients, shrinking less important predictors to zero, thereby enabling automatic variable selection and reducing overfitting. The optimal cutoff score was determined using Youden's index (sensitivity + specificity - 1). Decision curve analysis (DCA) was performed to evaluate the clinical utility of the model across a range of threshold probabilities (5%–95%) by calculating the net benefit relative to the "treat-all" and "treat-none" strategies. All statistical tests were two-sided, and a P-value < 0.05 was considered statistically significant.

3 Results

3.1 General Characteristics

A total of 133 patients with PAS were enrolled in this study, with a mean age of 31.69 ± 4.37 years and a mean gestational age at delivery of 36.11 ± 1.12 weeks. Among them, 49 cases (36.84%) experienced severe adverse maternal outcomes, while 84 cases (63.16%) did not.

As shown in Table 1, there were no statistically significant differences between the two groups except for the distribution of the degree of placental invasion ($P < 0.001$). Notably, the incidence of placenta percreta in SAMO group was significantly higher than that in the non-SAMO group (57.1% vs. 1.2%, $P < 0.001$).

Table 1
Demographic, obstetric, and placental characteristics of PAS patients.

Characteristic	Non-SAMO (n = 84)	SAMO (n = 49)	F/ χ^2	P-value
Maternal age (years), Mean $\pm$ SD	31.57 $\pm$ 4.02	31.90 $\pm$ 4.93	1.765	0.186
Age $\geq$ 35 years, n (%)	15 (20.0)	10 (28.6)	0.008	0.337
Gestational age at delivery (weeks), Mean $\pm$ SD	36.18 $\pm$ 1.28	36.01 $\pm$ 0.87	0.931	0.336
Pre-delivery BMI $\geq$ 28 kg/m ² , n (%)	27 (36.0)	10 (28.6)	4.912	0.519
IVF-ET conception, n (%)	51 (60.7)	23 (46.9)	2.379	0.087
Number of prior cesarean deliveries			6.933	0.074
0	10 (10.8)	1 (1.6)	4.814	0.051
1	65 (69.9)	38 (60.3)	1.535	0.143
2	8 (9.5)	10 (20.4)	1.945	0.204
$\geq$ 3	1 (1.2)	0	0.682	1.00
Interval since last cesarean (years), Mean $\pm$ SD	6.54 $\pm$ 3.37	6.14 $\pm$ 3.77	0.058	0.468
$\geq$ 3 induced abortions, n (%)	20 (26.7)	10 (28.6)	0.428	0.822
Gestational hyperglycemia ^a , n (%)	20 (26.7)	6 (17.1)	1.376	0.340
Gestational hypertensive disorders ^b , n (%)	4 (5.3)	0	0.633	0.305
Antepartum bleeding, n (%)	39 (52.0)	20 (57.1)	0.528	0.383
Emergency surgery for bleeding > 300mL, n (%)	15 (20.0)	6 (17.1)	0.741	0.470
Degree of placental invasion			66.633	< 0.001
Accreta (%)	50 (59.5)	3 (6.1)	40.203	< 0.001
Increta (%)	33 (39.3)	18 (36.7)	0.816	0.390
Percreta (%)	1 (1.2)	28 (57.1)	46.678	< 0.001
<i>Note: BMI: Body Mass Index. ^a Includes pre-gestational diabetes, prediabetes, and gestational diabetes mellitus. ^b Includes gestational hypertension and preeclampsia (no eclampsia occurred in the study population).</i>				

3.2 Variable Selection and Model Development

LASSO logistic regression with 5-fold cross-validation was performed to select the optimal regularization parameter. As shown in the cross-validation curve, peak predictive performance was achieved at $\log_{10}(\lambda) = 0.36$, corresponding to $\lambda = 2.3101$ (Fig. 2). This process selected 11 independent predictors from the initial 21 imaging signs. However, to develop a clinically interpretable integer-based scoring system, we excluded increased subplacental vascularity, intraplacental flow-void vessels, and bridging vessels from the final model because their regression coefficients were close to zero and they contributed minimally to risk prediction. Consequently, eight predictors were retained in the simplified scoring system. The coefficients and assigned weights for each variable are detailed in Table 2. The most prominent risk factors identified were the degree of placenta previa (weight: 2), intraplacental T2-weighted (T2WI) hypointense bands (weight: 2), and the "tenting sign" (weight: 2). Other contributing factors, including placental location, placental thickness, placental lacunae, cervical length, and myometrial thinning, were each assigned a weight of 1.

Table 2

Predictors selected by LASSO regression with their regression coefficients and assigned weights.

Predictor	β Coefficient	Weight
Ultrasound Features		
Placental location	1.1364	1
Degree of placenta previa	2.1151	2
Placental thickness	1.1131	1
Placental lacunae	0.994	1
Increased basal placental vascularity	0.4229	0
MRI Features		
Cervical length	0.9171	1
Myometrial thinning	1.4788	1
Intraplacental dark bands on T2WI	1.5582	2
Tenting sign	1.9038	2
Increased intraplacental flow voids	0.4724	0
Bridging vessels	0.6641	0
<i>Note: Although LASSO retained 11 variables with non-zero coefficients, three features (increased basal placental vascularity, increased intraplacental flow voids, and bridging vessels) were excluded from the final scoring system due to negligible effect sizes ($\beta < 0.5$) and were assigned a weight of 0 for clinical simplification.</i>		

3.3 Evaluation of the Weighted Scoring Model Performance

Based on the selected predictors and their respective weights, a combined ultrasound–MRI weighted scoring model was developed (Table 3). The total possible score of the model was 11 points. The LASSO logistic regression model based on predicted probabilities yielded an area under the curve (AUC) of 0.896 (95% CI: 0.833–0.958). After transforming the regression coefficients into an integer-based weighted scoring system, the score-based ROC curve demonstrated an AUC of 0.879 (95% CI: 0.812–0.945; Fig. 3). The Hosmer–Lemeshow goodness-of-fit test indicated adequate calibration ($P = 0.076$).

Table 3
Detailed Scoring Criteria of the Ultrasound-MRI Weighted Scoring Model
for Predicting Severe Adverse Maternal Outcomes in Placenta Accreta
Spectrum

Predictor Variable	Feature Description	Score
Ultrasound Features		
Placental Location	Anterior placenta	1
	Posterior placenta	0
Placental Previa Severity	Complete previa	2
	Low-lying placenta	0
	No previa	0
Placental Thickness	≥ 5 cm	1
	< 5 cm	0
Placental Lacunae	Present	1
	Absent	0
MRI Features		
Cervical Length	< 2.5 cm	1
	≥ 2.5 cm	0
Myometrial Thickness	≤ 1 mm	1
	> 1 mm	0
T2WI Intraplacental Hypointense Band	Present	2
	Absent	0
Tent Sign	Present	2
	Absent	0

Using Youden’s index, the optimal cutoff value for the model was identified as 7 points (Fig. 3). At this threshold, the model achieved 75.51% sensitivity (95% CI: 62.69–87.48%), 88.10% specificity (95% CI:

79.96–95.12%). Women with scores ≥ 7 had a significantly higher risk of SAMO (OR = 22.82, 95% CI: 9.03–57.68; $P < 0.001$).

The distribution of total scores differed significantly between groups (Fig. 4): the SAMO group had a median score of 8 (IQR: 7–9), while the non-SAMO group had a median score of 5 (IQR: 4–6; $P < 0.001$). Notably, 39 of 49 women (79.59%) in the SAMO group scored ≥ 7 points, compared with only 13 of 84 women (15.48%) in the non-SAMO group.

3.4 Clinical Utility Assessment

Decision curve analysis (DCA) demonstrated that the model provided a positive net benefit across a broad range of threshold probabilities (approximately 0.05–0.85), outperforming both the “treat-all” strategy (assuming SAMO for all patients) and the “treat-none” strategy (assuming no SAMO) (Fig. 5). The maximum net benefit of the model was approximately 0.29 at low threshold probabilities (around 5–10%). The model maintained superiority over the “treat-all” strategy even at the higher thresholds, whereas the latter yielded a negative net benefit beyond a threshold probability of approximately 35%. These findings suggest that incorporating the model into clinical decision-making could provide meaningful clinical benefit by improving risk stratification and optimizing resource allocation compared with universal treatment or no-intervention strategies.

4 Discussion

In the present study, we developed and validated a weighted scoring model that integrates ultrasound and MRI features using least absolute shrinkage and selection operator LASSO logistic regression to predict SAMO in patients with PAS. The model demonstrated strong discriminative ability, with an area under the receiver operating characteristic curve (AUC) of 0.879, and identified a clinically meaningful threshold of 7 or more points for risk stratification. Our analysis showed no statistically significant differences between the SAMO and non-SAMO groups in terms of maternal demographic characteristics or pregnancy complications, with the exception of the degree of placental invasion. Notably, although the depth of placental invasion was associated with adverse outcomes, 43% (21 of 49) of patients who experienced SAMO did not have placenta percreta. This observation highlights the value of incorporating multimodal imaging features beyond invasion depth alone for predicting clinical outcomes and suggests that placental invasion grade is not the sole determinant of SAMO. Consistent with this, Xin et al. reported that PAS involving cervical implantation is associated with significantly worse maternal outcomes, emphasizing the importance of preoperative identification of high-risk imaging features^[22]. On the other hand, excessive intervention may also be associated with adverse outcomes. A study published in *JAMA* reported that prophylactic measures such as arterial balloon occlusion are associated with an increased risk of all-cause maternal mortality^[23]. Therefore, unlike existing prediction models that primarily focus on the diagnostic accuracy of placental invasion depth^[9, 11], our model directly targets clinically relevant endpoints, including hysterectomy and massive hemorrhage. By

enabling more precise risk stratification, this approach may help reduce unnecessary interventions in low-risk patients and provide more practical guidance for individualized clinical decision-making.

The complementary roles of ultrasound and MRI in PAS evaluation have been well established^[9]. Ultrasound provides superior assessment of placental vascularity and the bladder-uterine interface, while MRI excels in evaluating invasion depth, placental bulging, and relationships with adjacent structures, particularly for posterior placentas^[7, 24–26]. Our study integrated the advantages of multimodal imaging to compensate for the limitations of individual examinations. This approach is consistent with the multi-parameter evaluation strategy recommended by the FIGO guidelines^[7].

Various predictive scoring models for PAS have been developed in existing literature. Knight et al.^[9] demonstrated that the combined use of ultrasound and MRI achieved a sensitivity of 56% and a specificity of 92% for assessing PAS. Xia et al.^[11] developed a diagnostic model based on 11 MRI features with an AUC of 0.874. Although a recently constructed nomogram by Zuo et al.^[12] enables simultaneous PAS diagnosis, subtype classification, and adverse outcome prediction (AUC = 0.822), its integration of radiomic features limits its clinical operability. Our study shares a similar objective with the recent work of Cao et al.^[14], who developed a nomogram to predict the need for massive transfusion in a highly specific subgroup of patients. Although their model demonstrated excellent predictive performance (AUC > 0.90), its clinical utility is constrained by its applicability only to patients with anterior placenta previa and a history of cesarean delivery, as well as its reliance on intraoperative variables that are not available for preoperative decision-making. In contrast, our model is designed for the broader population of patients with placenta accreta spectrum and is based solely on prenatal imaging features, thereby facilitating early risk assessment, timely intervention, and proactive mobilization of medical resources.

Furthermore, the application of LASSO regression addresses a critical methodological challenge in prediction modeling. Traditional scoring systems often fail to account for multicollinearity among imaging features, leading to unstable parameter estimates and poor generalizability^[15]. By implementing L1 regularization, our model simultaneously performs variable selection and coefficient estimation while effectively mitigating the risk of overfitting, a critical advantage given the constraints of our sample size. This methodological rigor sets our approach apart from existing prediction models for placenta accreta spectrum, including the model developed by An et al., which relied on conventional logistic regression and did not account for potential correlations among predictive features^[27].

The eight predictors identified in this study are supported by clear pathophysiological mechanisms. The degree of placenta previa reflects the area of villous invasion, as placenta previa (especially the complete type) is frequently associated with extensive adhesions. Increased placental thickness (≥ 5 cm) suggests placental vascular hyperplasia and abnormal perfusion. Placental lacunae, appearing as intraplacental anechoic areas, represent intraplacental hemorrhage or edema and are closely linked to abnormal invasion^[24, 28]. Regarding MRI signs, a shortened cervical length (< 2.5 cm) suggests placental

invasion into the cervical region, which increases the difficulty of separation. Myometrial thinning (≤ 1 mm) reflects the destruction of the myometrium by invading placental tissue. Intraplacental T2-weighted (T2WI) low-signal bands represent fibrin deposition within the placenta, commonly observed in severe PAS. The "tenting sign" (elevation of the uterine serosa) directly indicates that the placenta has penetrated the myometrium and involved the serosa, serving as a strong predictor of hysterectomy [29]. The assigned weights (1–2 points) for these signs reflect their relative contribution to adverse outcomes, aligning with clinico-pathological expectations.

Our model's clinical utility extends beyond statistical performance metrics. The scoring model developed in this study utilizes a cutoff of 7 points to indicate the risk of severe adverse outcomes, thereby guiding prenatal prophylactic management. A score of ≥ 7 necessitates advanced preparations for potential intraoperative hysterectomy and massive blood transfusion. What's more, our model demonstrates positive net benefit across a broad range of threshold probabilities (approximately 0.05–0.85), substantially outperforming both "treat-all" and "treat-none" strategies. This aligns closely with the hierarchical diagnosis and treatment concept for PAS proposed by Luo et al. [8]. Furthermore, compared with the recent radiomics-based model by Zou et al. [30], our model demonstrated a slightly lower AUC (0.879 vs. 0.905); however, it does not require complex software support, making it more suitable for widespread implementation in medical institutions with limited resources.

5 Limitations

This study has several limitations. First, its retrospective, single-center design may introduce selection bias. Second, although LASSO regression effectively addressed multicollinearity, the influence of residual confounding factors cannot be entirely excluded. Third, the proposed model has not yet undergone external validation. Furthermore, the high cost of MRI remains a significant constraint, limiting its widespread use in primary healthcare settings. Future research should focus on identifying the optimal clinical indications for MRI to ensure cost-effectiveness.

Future research should prioritize prospective external validation across diverse healthcare settings. Implementation studies evaluating the model's impact on clinical outcomes and healthcare utilization would provide valuable evidence for clinical adoption.

6 Conclusion

In conclusion, the LASSO-based weighted scoring model integrating ultrasound and MRI features demonstrates strong predictive performance for severe adverse maternal outcomes in patients with placenta accreta spectrum. Key predictors identified by the model include placental location, placenta previa, placental thickness, placental lacunae, cervical length, myometrial thinning, intraplacental T2WI dark bands, and the tenting sign. With an AUC of 0.879 and an optimal cutoff value of 7 points, the model provides a practical and objective tool for risk stratification and individualized management of PAS patients. Application of this model may facilitate multidisciplinary collaboration, optimize resource

allocation, and improve maternal outcomes. Future studies should prioritize multicenter prospective validation and explore implementation strategies suitable for diverse clinical settings, particularly in resource-limited environments.

Declarations

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Human Ethics and Consent to Participate Declarations

This study was approved by the Institutional Review Board (Ethics Committee) of Chengdu Women's and Children's Central Hospital (Approval No.: Scientific Research Ethics B2018(8)). Written informed consent was not required because of the retrospective nature of the review. All methods were carried out in accordance with relevant guidelines and regulations.

Author contributions

All authors made a diverse contribution to the work reported. TZ, SW, HG and YL participated in the study design and data collection. TZ, SW, HG and YL analyzed and interpreted the data and drafted the manuscript. All authors collected and analyzed the data. TZ, DL and YL reviewed and edited the manuscript. TZ, DL and YL have been working for data recording. All authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interests.

Consent to Publish declaration

Not applicable

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Figures

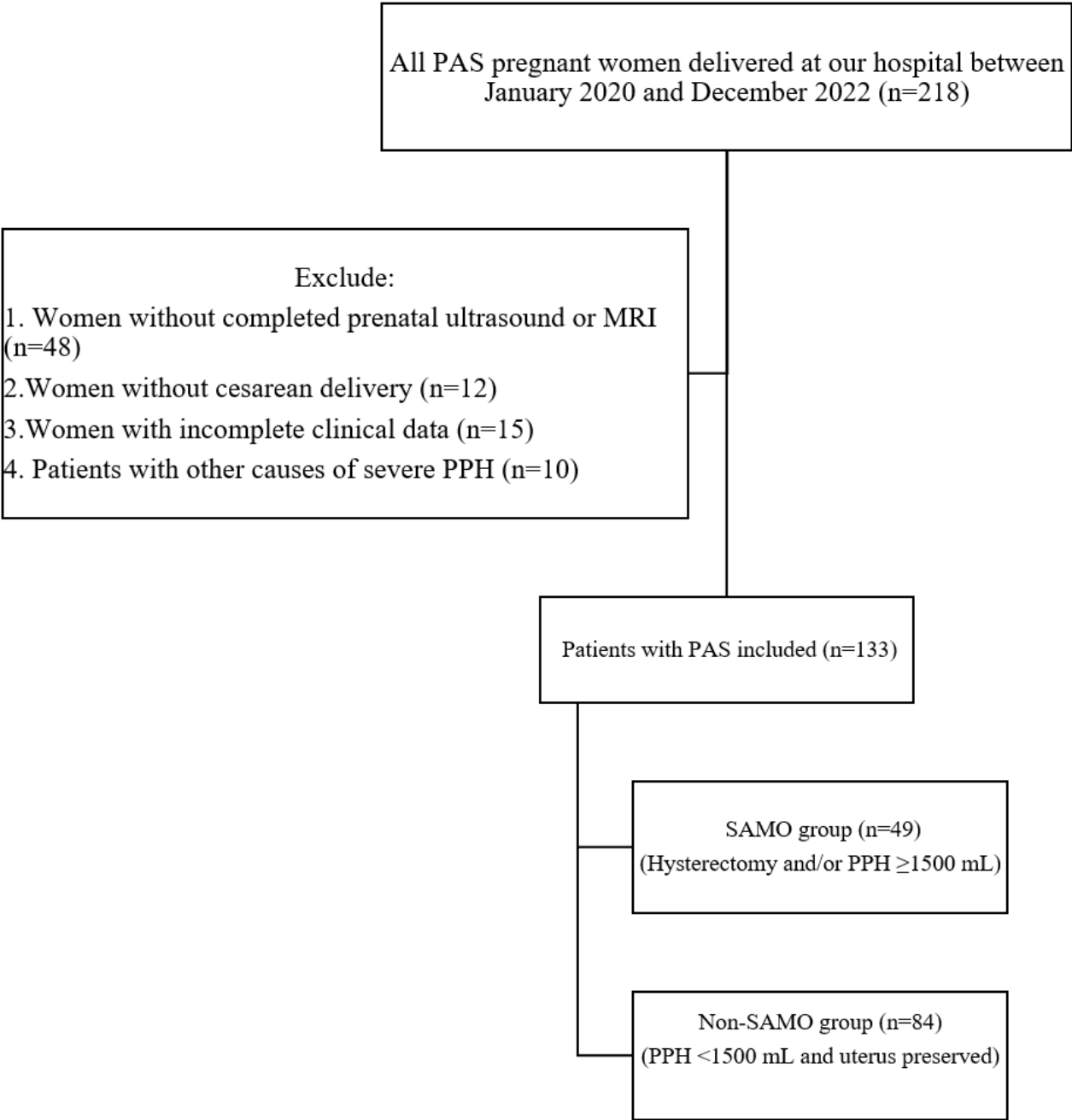


Figure 1

The screen process of the participants.

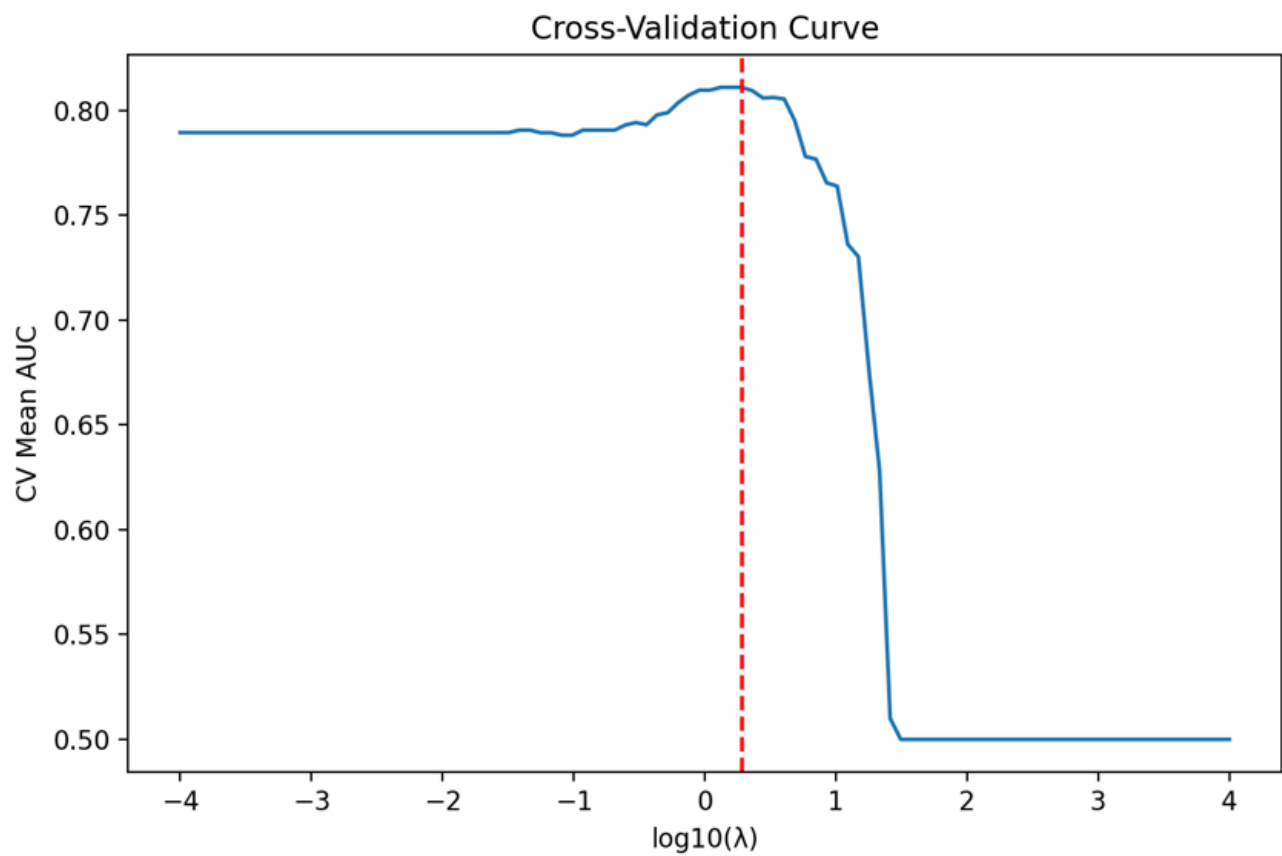


Figure 2

The cross-validation curve

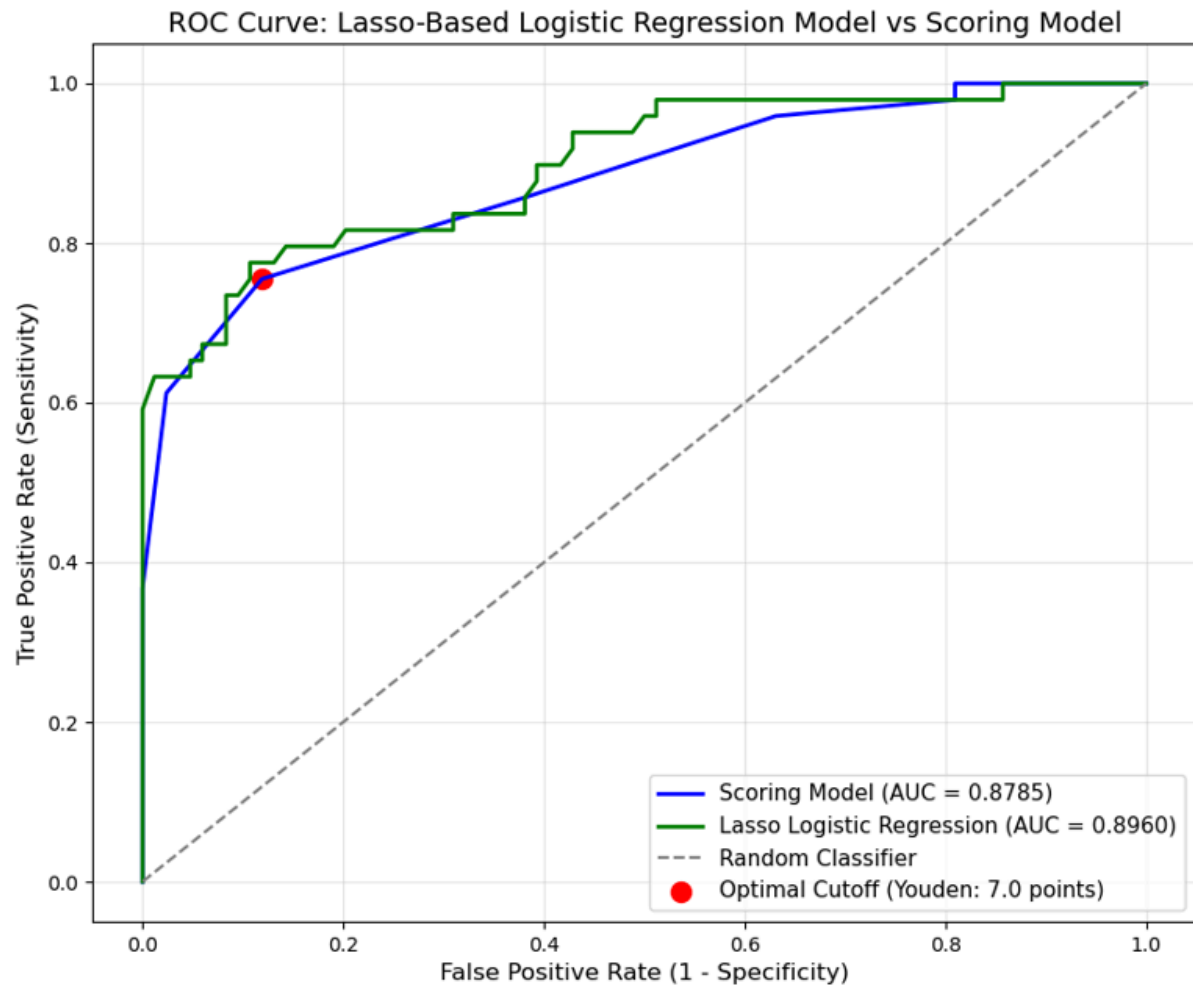


Figure 3

ROC curve of the LASSO logistic regression-based ultrasound-combined MRI weighted scoring model for predicting severe adverse outcomes in PAS.

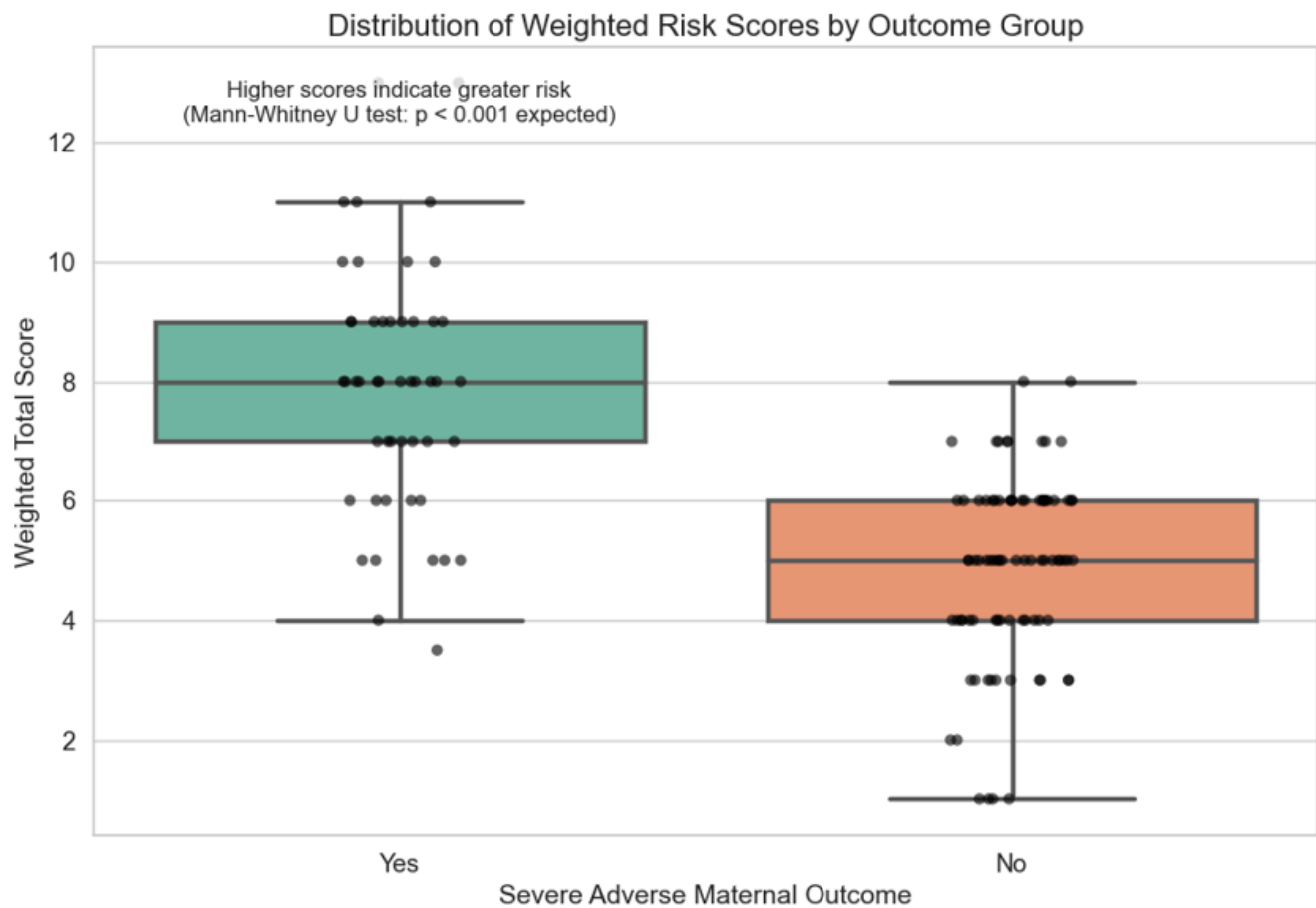


Figure 4

Distribution of total weighted risk scores stratified by severe adverse maternal outcome.

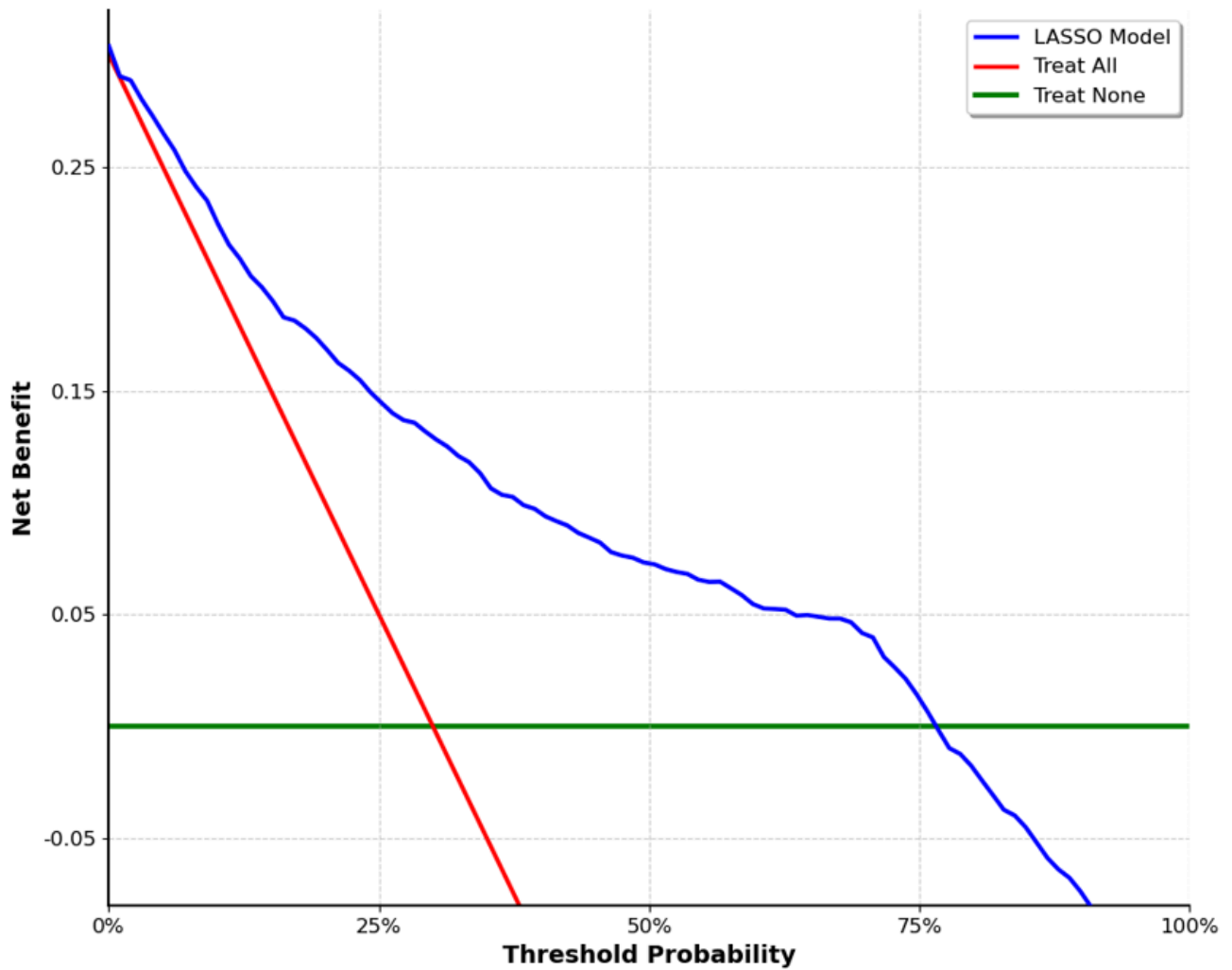


Figure 5

Decision curve analysis of the LASSO-based ultrasound–MRI model for predicting severe adverse maternal outcomes in placenta accreta spectrum.