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ORIGINAL RESEARCH

# Diagnostic Value of Combined MRI and Ultrasound Features in Invasive Placenta Accreta and Prediction of Adverse Outcomes

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**Objective:** This study aimed to evaluate the diagnostic value of magnetic resonance imaging (MRI) combined with ultrasound features in invasive placenta accreta and to assess their effectiveness in predicting adverse clinical outcomes.

**Methods:** A retrospective analysis was conducted on 173 pregnant women with suspected placenta accreta who were admitted to our hospital between March 2022 and May 2024. Surgical or pathological findings served as the diagnostic criteria. Patients were divided into an invasive placenta accreta group (n=104; including accreta and percreta) and a non-invasive group (n=69; including no placenta accreta or placenta adherent types). Baseline characteristics, MRI, and ultrasound features were compared between groups. Logistic regression was used to identify independent risk factors, and receiver operating characteristic (ROC) curves were applied to evaluate the diagnostic performance of MRI, ultrasound, and their combination. The invasive placenta accreta group was further classified into an adverse outcome subgroup (n=48; defined as intraoperative blood loss ≥1500 mL and/or hysterectomy) and a good outcome subgroup (n=56). The diagnostic value of imaging features for predicting adverse outcomes was analyzed.

**Results:** Independent risk factors for invasive placenta accreta included myometrial thinning, low placental T2WI signal, blurred uteroplacental interface, abnormal placental vascular proliferation, localized bulging, loss of retroplacental space, moth-eaten placental changes, disrupted blood flow at the placental base, and ultrasound score (all P<0.05). The combined diagnosis achieved the highest diagnostic performance, with an AUC of 0.932 (95% CI: 0.876–0.965), sensitivity of 96.53%, and specificity of 91.91%, outperforming individual features. For predicting adverse outcomes, the combined model also demonstrated excellent accuracy, with an AUC of 0.941 (95% CI: 0.868–0.974), sensitivity of 93.06%, and specificity of 94.22%.

**Conclusion:** MRI and ultrasound imaging features can be used independently or jointly in diagnosing invasive placenta accreta and predicting related adverse outcomes. The combined approach provides significantly better diagnostic accuracy and clinical value than either modality alone.

**Keywords:** magnetic resonance imaging, ultrasound, combined diagnosis, invasive placenta accreta, adverse outcomes, predictive value

## Introduction

Invasive placenta accreta is a severe pregnancy complication characterized by the abnormal invasion of placental villi into the uterine myometrium, sometimes even penetrating the uterine wall.[1] In recent decades, its incidence has shown a rising trend globally, reported at approximately 0.2%–0.9% of all pregnancies, with higher rates in regions where cesarean section rates continue to increase.[2] The growing use of assisted reproductive technologies further contributes to this upward trend. This condition significantly elevates the risk of postpartum hemorrhage, uterine rupture, and amniotic fluid embolism, and in severe cases, may result in hysterectomy or even maternal and perinatal mortality.[3] Early diagnosis and timely intervention are therefore essential for improving pregnancy outcomes.

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Traditionally, diagnosis relied on intraoperative direct visualization and pathological confirmation, which are often delayed until delivery, thereby increasing the risk of severe complications.[4] With advancements in medical imaging, non-invasive early diagnosis has become possible. Ultrasound, recommended as the first-line modality in current clinical guidelines, is widely used due to its accessibility, low cost, and real-time capability for assessing the relationship between the placenta and the uterus.[5] However, ultrasound accuracy is easily affected by maternal habitus, fetal position, and placental location, which may result in suboptimal sensitivity and specificity, especially in cases of deep placental invasion or atypical presentation.[6]

Magnetic resonance imaging (MRI) has emerged as an important complementary diagnostic tool because of its high spatial resolution, multiplanar capability, and absence of ionizing radiation.[7] MRI allows clear visualization of myometrial thinning, uteroplacental interface integrity, abnormal intraplacental signals, and vascular changes, and is particularly valuable in detecting placenta percreta.[8] Moreover, T2-weighted imaging (T2WI) provides unique advantages for identifying low-signal intensity lesions and localized bulging, thereby offering more intuitive pathological evidence.[9] Nevertheless, the widespread clinical use of MRI is limited by higher cost, longer examination times, and the need for patient cooperation.

Recent studies have indicated that combining ultrasound with MRI can effectively improve diagnostic performance, integrating the dynamic real-time monitoring strengths of ultrasound with the high-resolution anatomical detail of MRI.[10] However, previous research has often been constrained by small sample sizes, single-modality assessments, or insufficient exploration of their predictive value for adverse maternal and perinatal outcomes. Thus, further systematic evaluation is warranted.

On this basis, the present study aimed to comprehensively analyze the diagnostic value of MRI and ultrasound features, both independently and in combination, for invasive placenta accreta, and to further investigate their predictive significance for adverse outcomes. This work seeks to provide evidence-based insights for optimizing diagnostic strategies and improving maternal–fetal prognosis.

# Materials and Methods

## General Information and Inclusion Criteria

This retrospective study analyzed the clinical and imaging data of 173 pregnant women suspected of placenta accreta who were admitted to our hospital between March 2022 and May 2024.

Inclusion criteria were as follows: (1) Pregnant women in mid-to-late pregnancy (≥20 gestational weeks), aged 18–45 years, with a clear obstetric history; (2) singleton pregnancy; (3) completion of both MRI and ultrasound examinations with imaging data of sufficient quality for evaluation; (4) diagnosis of placenta accreta type confirmed through intraoperative observation or pathological examination (used as the diagnostic gold standard); (5) written informed consent obtained from all participants and their families.

Exclusion criteria were: (1) severe comorbidities (eg, gestational hypertension, diabetes, cardiovascular disease, malignant tumors) that might interfere with diagnosis or outcomes; (2) inadequate imaging quality due to artifacts, fetal position, or other technical issues; (3) concurrent placental abnormalities (eg, abruption, tumors); (4) acute infectious diseases affecting pelvic imaging features; (5) contraindications for MRI or ultrasound (eg, metal implants, contrast allergy); (6) severe psychiatric illness or cognitive impairment preventing cooperation; (7) incomplete participation in study procedures.

Based on intraoperative and pathological confirmation, patients were categorized into the observation group (n = 104; invasive placenta accreta, including increta and percreta types) and the control group (n = 69; non-invasive placenta accreta, including normal placenta or placenta adherent). Among women with invasive placenta accreta, those with intraoperative blood loss ≥1500 mL and/or hysterectomy[11] were classified as the Group A (n = 48, poor outcome), while the remaining were classified as the Group B (n = 56, good outcome).

This study was approved by the ethics committee of Jinan Maternal and Child Health Hospital (Approval No.: RS-24-ZD0019), and it complied with the Declaration of Helsinki and relevant national regulations.

# Methods

## MRI Examination

MRI examinations were performed using a Siemens VIDA 3.0T scanner, with patients in a supine position. The scanning range extended from the upper edge of the pubic symphysis to the uterine fundus. Sequences included sagittal, axial, and coronal T2WI, axial T1WI, and fat-suppressed T2WI sequences. Parameters: slice thickness 4 mm, interslice spacing 5.2 mm; T1WI echo time (TE) 9–20 ms, repetition time (TR) 450–600 ms; T2WI TE 80–120 ms, TR 3000–4500 ms.

Two radiologists (each with >5 years of experience in obstetric imaging) independently reviewed the images under blinded conditions (blinded to patients' clinical data and outcomes). The following MRI features were evaluated: myometrial thinning, low T2WI signal within the placenta, uteroplacental interface clarity, intraplacental signal uniformity, abnormal vascular proliferation, focal bulging of placenta/uterus, and bladder wall abnormalities. Interobserver agreement was assessed using the kappa statistic to evaluate reliability.

## Ultrasound Examination

Ultrasound examinations were performed using a Mindray R9s Doppler system with patients in a supine position and a moderately filled bladder. Both abdominal probes (3.5–5.0 MHz) and high-frequency probes (7.0–10.0 MHz) were used. The following ultrasound features were assessed: placental location and thickness, lacunae, disappearance of the retroplacental space, moth-eaten changes, and disordered blood flow at the placental base.

Ultrasound findings were scored using a standardized placenta accreta scoring system.[12] A score ≥3 was taken as the diagnostic threshold for placenta accreta. Two senior sonographers independently evaluated all images in a blinded fashion, with interobserver variability assessed by kappa analysis.

## Observational Indicators

### Comparison of Clinical Data

Baseline clinical data were compared between the observation group (invasive placenta accreta) and the control group (non-invasive placenta accreta), including age, body mass index (BMI), gestational weeks, gravidity, parity, history of induced abortion, and history of cesarean section.

### MRI and Ultrasound Feature Analysis

Differences in MRI and ultrasound imaging features between the two groups were recorded and compared.

### Risk Factor Analysis for Invasive Placenta Accreta

Independent risk factors for invasive placenta accreta were identified using multivariate logistic regression analysis.

### Imaging Features of Patients with Poor Outcomes

Patients with invasive placenta accreta were divided into poor outcome group (Group A) and good outcome group (Group B) based on clinical outcomes, and the MRI and ultrasound imaging features of the two groups were analyzed.

### Evaluation of Diagnostic Efficiency

Based on ROC curves, the diagnostic and predictive values of MRI and ultrasound imaging features for invasive placenta accreta and poor outcomes were evaluated, and the accuracy of single imaging indicators versus combined diagnosis was compared.

## Statistical Analysis Methods

GraphPad Prism 8 was used for plotting, and SPSS 22.0 software was used for statistical analysis. Categorical data were expressed as percentages (%) and analyzed using the $\chi^2$-test. Continuous data were expressed as ($\bar{x} \pm s$) and compared between groups using an independent sample *t*-test. Multivariate logistic regression analysis was performed to identify risk factors for invasive placenta accreta. ROC curve analysis was used to evaluate the diagnostic value of MRI and ultrasound imaging features for invasive placenta accreta and their predictive efficacy for poor outcomes. Sample size was not determined by priori power calculation, but the total of 173 cases over two years was considered adequate for detecting clinically meaningful differences in this relatively rare condition. A significance level of α=0.05 was used, with P<0.05 indicating statistical significance.

# Results

## Comparison of Clinical Data

A total of 173 suspected cases of placental implantation were categorized into two groups after classification: the observation group (n=104, invasive placental implantation, including 98 cases of implantation type [56.65%] and 7 cases of penetration type [4.05%]) and the control group (n=69, non-invasive placental implantation, including 30 cases of non-implantation [17.34%] and 38 cases of adhesive placenta [21.97%]). There were no statistically significant differences between the observation and control groups in terms of age, BMI, gestational weeks, number of pregnancies, multiparity, history of induced abortion, and cesarean section history (P>0.05) (Table 1).

## Comparison of MRI Imaging and Ultrasonographic Features

Significant differences were observed between the observation and control groups in the following characteristics: thinning of the myometrium, low T2WI signal within the placenta, blurred uteroplacental interface, heterogeneous vascular signal within the placenta, abnormal vascular proliferation within the placenta, focal bulging of the placenta/ uterus, bladder wall prominence, loss of retroplacental space, moth-eaten changes within the placenta, disrupted blood flow at the placental base, and ultrasonographic feature scores (P<0.05) (Table 2).

## Interobserver Agreement

Two radiologists independently interpreted MRI images, and two senior sonographers independently evaluated ultrasound images. Interobserver agreement was good to excellent, with kappa values ranging from 0.76 to 0.85 for MRI features and from 0.72 to 0.83 for ultrasound features, indicating satisfactory reproducibility of imaging interpretation.

**Table 1** Comparison of Clinical Data ($\bar{x} \pm s$, n [%])

| | Observation (n=104) | Control (n=69) | $t/x^2$ | *P* |
|---|---|---|---|---|
| Age (years) | 31.79±2.56 | 32.11±2.29 | 0.839 | 0.402 |
| BMI (kg/m²) | 26.32±3.15 | 25.97±3.41 | 0.692 | 0.489 |
| Gestational weeks | 33.86±2.54 | 34.19±2.48 | 0.844 | 0.399 |
| Number of pregnancies | 2.46±0.75 | 2.37±0.82 | 0.744 | 0.457 |
| Multiparity | 95 (91.35) | 62 (89.86) | 0.109 | 0.740 |
| History of abortion | 70 (67.31) | 51 (73.91) | 0.860 | 0.353 |
| Cesarean history | 73 (70.19) | 47 (68.12) | 0.084 | 0.771 |

**Table 2** Comparison of MRI Imaging and Ultrasonographic Features ($\bar{x} \pm s$, n [%])

| Imaging Features | Observation (n=104) | Control (n=69) | $t/x^2$ | *P* |
|---|---|---|---|---|
| Thinning of the myometrium | 79 (75.96) | 41 (59.42) | 5.340 | 0.020 |
| Low T2WI signal within the placenta | 40 (38.46) | 13 (18.84) | 7.514 | 0.006 |
| Blurred uteroplacental interface | 70 (67.31) | 31 (44.93) | 8.550 | 0.003 |
| Heterogeneous vascular signal within placenta | 59 (56.73) | 27 (39.13) | 5.139 | 0.023 |
| Abnormal vascular proliferation within placenta | 66 (63.46) | 30 (43.48) | 6.706 | 0.009 |
| Focal bulging of placenta/uterus | 42 (40.38) | 8 (11.59) | 16.732 | <0.001 |
| Bladder wall prominence | 65 (62.50) | 31 (44.93) | 5.186 | 0.022 |
| Loss of retroplacental space | 74 (71.15) | 17 (24.64) | 35.998 | <0.001 |
| Moth-eaten changes within placenta | 51 (49.04) | 6 (8.70) | 30.558 | <0.001 |
| Disrupted blood flow at placental base | 32 (30.77) | 9 (13.04) | 7.207 | 0.007 |
| Ultrasonographic feature scores | 4.02±1.15 | 1.38±0.34 | 18.523 | <0.001 |

## Multivariate Logistic Regression Analysis of Factors Influencing Invasive Placental Implantation

Using invasive placental implantation as the dependent variable (yes=1, no=0) and statistically significant variables from Table 1 and Table 2 as independent variables, a multivariate logistic regression analysis model was constructed. Results revealed that thinning of the myometrium, low T2WI signal within the placenta, blurred uteroplacental interface, abnormal vascular proliferation within the placenta, focal bulging of the placenta/uterus, loss of retroplacental space, moth-eaten changes within the placenta, disrupted blood flow at the placental base, and ultrasonographic feature scores were independent influencing factors for invasive placental implantation ($P<0.05$) (Tables 3, 4). Model fitting statistics: likelihood ratio $\chi^2 = 112.36$, $P < 0.001$; Nagelkerke $R^2 = 0.62$, suggesting a good explanatory ability of the model.

## Diagnostic Value of MRI Imaging and Ultrasonographic Features in Invasive Placenta Accreta

Using the observation group as the positive sample and the control group as the negative sample, the ROC curve of MRI imaging and ultrasonographic features in diagnosing invasive placenta accreta was plotted (Figure 1). The AUC, sensitivity, and specificity of each feature and their combined diagnosis are shown in Table 5. The ROC analysis demonstrated that the combined diagnostic model, constructed from the logistic regression probability score, yielded the highest accuracy (AUC = 0.932, 95% CI: 0.876–0.965; sensitivity = 96.53%; specificity = 91.91%). Statistical comparison of AUCs: Using the DeLong test, the combined diagnostic model significantly outperformed either MRI or ultrasound features alone ($P < 0.01$).

**Table 3** Variable Assignment Table

| Variable | Assignment |
|---|---|
| Thinning of the myometrium | Yes=1, No=0 |
| Low T2WI signal within placenta | Yes=1, No=0 |
| Blurred uteroplacental interface | Yes=1, No=0 |
| Heterogeneous vascular signal | Yes=1, No=0 |
| Abnormal vascular proliferation | Yes=1, No=0 |
| Focal bulging of placenta/uterus | Yes=1, No=0 |
| Bladder wall prominence | Yes=1, No=0 |
| Loss of retroplacental space | Yes=1, No=0 |
| Moth-eaten changes within placenta | Yes=1, No=0 |
| Disrupted blood flow at placental base | Yes=1, No=0 |
| Ultrasonographic feature scores | Actual value |

**Table 4** Multivariate Logistic Regression Analysis of Factors Affecting Invasive Placenta Accreta

| Factor | β | S.E. | Wald x² | P | OR | 95% CI |
|---|---|---|---|---|---|---|
| Thinning of the myometrium | 1.382 | 0.423 | 10.415 | <0.05 | 3.947 | 1.824~8.536 |
| Low T2WI signal within the placenta | 1.315 | 0.442 | 8.607 | <0.05 | 3.731 | 1.604~8.705 |
| Blurred uteroplacental interface | 1.421 | 0.508 | 7.9.13 | <0.05 | 4.120 | 1.659~10.172 |
| Uneven vascular signals in the placenta | 0.753 | 0.517 | 2.142 | >0.05 | 2.098 | 0.725~6.218 |
| Abnormal vascular proliferation within the placenta | 1.432 | 0.481 | 8.979 | <0.05 | 4.167 | 1.796~9.625 |
| Focal bulging of the placenta/uterus | 1.698 | 0.443 | 15.013 | <0.05 | 5.429 | 1.838~16.032 |
| Bladder wall protrusion | 0.759 | 0.485 | 2.376 | >0.05 | 2.148 | 0.693~6.536 |
| Loss of retroplacental space | 1.803 | 0.467 | 15.174 | <0.05 | 6.024 | 2.037~17.853 |
| Moth-eaten changes within the placenta | 1.740 | 0.477 | 13.485 | <0.05 | 5.682 | 1.971~16.387 |
| Disrupted blood flow at the placental base | 1.392 | 0.438 | 10.116 | <0.05 | 3.997 | 1.719~9.288 |
| Ultrasonographic features score | 1.748 | 0.412 | 17.769 | <0.05 | 5.608 | 1.963~16.052 |


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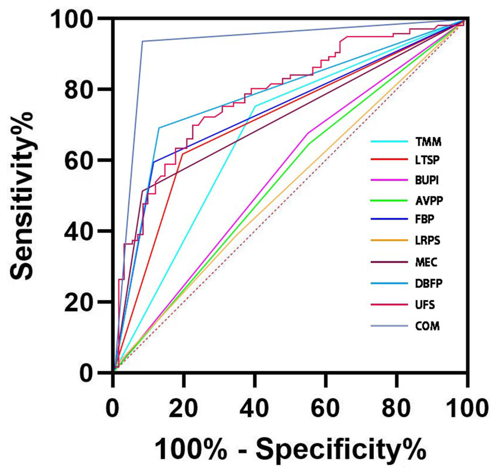


**Figure 1** ROC Curve for MRI Imaging and Ultrasonographic Features in Diagnosing Invasive Placenta Accreta.
**Abbreviations**: TMM, Thinning of the myometrium; LTSP, Low T2WI signal within the placenta; BUPI, Blurred uteroplacental interface; AVPP, Abnormal vascular proliferation within the placenta; FBP, Focal bulging of the placenta/uterus; LRPS, Loss of retroplacental space; MEC, Moth-eaten changes within the placenta; DBFP, Disrupted blood flow at the placental base; UFS, Ultrasonographic features score; COM, Combined.

## Comparison of MRI Imaging and Ultrasonographic Features Among Patients with Different Clinical Outcomes

Among the 104 patients with invasive placenta accreta, 48 had poor clinical outcomes (Group A), including 39 cases of intraoperative blood loss >1500 mL and 9 cases of hysterectomy. The remaining 56 patients had good clinical outcomes (Group B). There were statistically significant differences between Group A and Group B in terms of thinning of the myometrium, low T2WI signal within the placenta, blurred uteroplacental interface, abnormal vascular proliferation within the placenta, focal bulging of the placenta/uterus, loss of retroplacental space, moth-eaten changes within the placenta, disrupted blood flow at the placental base, and ultrasonographic features score ($P<0.05$). See Table 6.

## Diagnostic Value of MRI Imaging and Ultrasonographic Features for Adverse Outcomes in Patients with Invasive Placenta Accreta

Using patients with adverse outcomes as positive samples and those with good outcomes as negative samples, the ROC curve for MRI imaging and ultrasonographic features in diagnosing adverse outcomes of invasive placenta accreta was plotted (Figure 2). The AUC, sensitivity, and specificity of each feature and their combined diagnosis are shown in Table 7. ROC analysis showed that the combined diagnostic model (logistic regression probability score) achieved an AUC of 0.941 (95% CI: 0.868–0.974; sensitivity = 93.06%; specificity = 94.22%). Model fitting statistics: likelihood

**Table 5** Diagnostic Value of MRI Imaging and Ultrasonographic Features in Invasive Placenta Accreta

| Indicator | AUC | 95% CI | P | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|---|
| Thinning of the myometrium | 0.682 | 0.594~0.753 | <0.05 | 75.72 | 59.54 |
| Low T2WI signal within the placenta | 0.714 | 0.631~0.784 | <0.05 | 61.85 | 80.92 |
| Blurred uteroplacental interface | 0.562 | 0.480~0.638 | <0.05 | 67.05 | 45.09 |
| Abnormal vascular proliferation within the placenta | 0.547 | 0.465~0.627 | <0.05 | 63.58 | 44.51 |
| Focal bulging of the placenta/uterus | 0.743 | 0.662~0.811 | <0.05 | 59.54 | 88.44 |
| Loss of retroplacental space | 0.526 | 0.443~0.605 | <0.05 | 28.90 | 75.72 |
| Moth-eaten changes within the placenta | 0.718 | 0.639~0.787 | <0.05 | 50.87 | 91.91 |
| Disrupted blood flow at the placental base | 0.784 | 0.710~0.846 | <0.05 | 69.36 | 87.28 |
| Ultrasonographic features score | 0.787 | 0.714~0.852 | <0.05 | 70.52 | 77.91 |
| Combined diagnosis | 0.932 | 0.876~0.965 | <0.05 | 96.53 | 91.91 |

**Table 6** Comparison of MRI Imaging and Ultrasonographic Features Among Patients with Different Clinical Outcomes ($\bar{x} \pm s$, n[%])

| | Group A (n=48) | Group B (n=56) | t/x² | P |
|---|---|---|---|---|
| Thinning of the myometrium | 37 (77.08) | 27 (48.21) | 9.101 | 0.002 |
| Low T2WI signal within the placenta | 23 (47.92) | 10 (17.86) | 10.780 | 0.001 |
| Blurred uteroplacental interface | 34 (70.83) | 26 (46.43) | 6.306 | 0.012 |
| Abnormal vascular proliferation within the placenta | 33 (68.75) | 25 (44.64) | 6.089 | 0.013 |
| Focal bulging of the placenta/uterus | 20 (41.67) | 9 (16.07) | 8.420 | 0.003 |
| Loss of retroplacental space | 38 (79.17) | 15 (26.79) | 28.376 | <0.001 |
| Moth-eaten changes within the placenta | 32 (66.67) | 6 (10.71) | 34.895 | <0.001 |
| Disrupted blood flow at the placental base | 19 (39.59) | 9 (16.07) | 7.262 | 0.007 |
| Ultrasonographic features score (points) | 4.40±0.91 | 3.78±0.77 | 3.764 | <0.001 |

ratio $\chi^2$ = 89.52, P < 0.001; Nagelkerke $R^2$ = 0.57. DeLong test confirmed that the combined model significantly outperformed single imaging predictors (P < 0.01).

## Discussion

This study systematically analyzed the imaging features of MRI and ultrasound in diagnosing invasive placental implantation. The results showed significant differences between the observation group (invasive placental implantation) and the control group (non-invasive placental implantation) in several features, including thinning of the uterine myometrium, low T2WI signal within the placenta, unclear uterine myometrium-placenta interface, abnormal vascular proliferation within the placenta, localized bulging of the placenta/uterus, disappearance of the retroplacental space, moth-eaten changes within the placenta, disordered blood flow in the placental base, and ultrasound imaging scores (P < 0.05). These findings indicate that MRI and ultrasound imaging play an important role in diagnosing invasive placental implantation. However, each imaging modality has its own advantages, and their application should be tailored to the patient's specific circumstances or used in combination. Due to its high soft tissue resolution, MRI provides clear visualization of the thickness of the uterine myometrium, internal placental signal characteristics, and the relationship between the placenta and surrounding tissues, offering clinicians more intuitive and detailed information.[13,14] However, the high cost of MRI equipment and the long examination time require pregnant women to remain still during the scan, which may cause discomfort, especially for patients with pregnancy complications. Ultrasound, due to its real-time

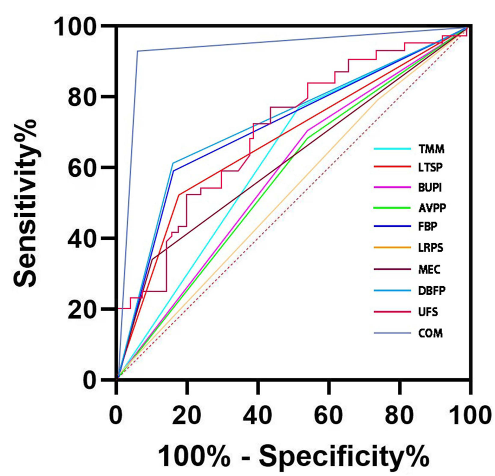


**Figure 2** ROC Curve for MRI Imaging and Ultrasonographic Features in Diagnosing Adverse Outcomes of Invasive Placenta Accreta.

**Abbreviations**: TMM, Thinning of the myometrium; LTSP, Low T2WI signal within the placenta; BUPI, Blurred uteroplacental interface; AVPP, Abnormal vascular proliferation within the placenta; FBP, Focal bulging of the placenta/uterus; LRPS, Loss of retroplacental space; MEC, Moth-eaten changes within the placenta; DBFP, Disrupted blood flow at the placental base; UFS, Ultrasonographic features score; COM, Combined.

**Table 7** Diagnostic Value of MRI Imaging and Ultrasonographic Features for Adverse Outcomes in Patients with Invasive Placenta Accreta

| Indicator | AUC | 95% CI | P | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|---|
| Thinning of the myometrium | 0.629 | 0.518~0.726 | <0.05 | 77.46 | 47.98 |
| Low T2WI signal within the placenta | 0.674 | 0.569~0.763 | <0.05 | 55.49 | 82.08 |
| Blurred uteroplacental interface | 0.585 | 0.473~0.681 | <0.05 | 70.52 | 46.24 |
| Abnormal vascular proliferation within the placenta | 0.573 | 0.464~0.675 | <0.05 | 68.21 | 45.66 |
| Focal bulging of the placenta/uterus | 0.718 | 0.615~0.807 | <0.05 | 58.96 | 83.82 |
| Loss of retroplacental space | 0.531 | 0.426~0.637 | <0.05 | 79.77 | 26.01 |
| Moth-eaten changes within the placenta | 0.624 | 0.516~0.728 | <0.05 | 34.10 | 90.17 |
| Disrupted blood flow at the placental base | 0.730 | 0.624~0.813 | <0.05 | 61.27 | 83.82 |
| Ultrasonographic features score | 0.705 | 0.602~0.798 | <0.05 | 77.46 | 56.07 |
| Combined diagnosis | 0.941 | 0.868~0.974 | <0.05 | 93.06 | 94.22 |

nature, convenience, and lower cost, is widely used in obstetric imaging.[15] In particular, transabdominal and transvaginal ultrasound allows dynamic observation of placental implantation sites and basal blood flow, providing strong support for initial screening of placental implantation.[16] However, the diagnostic performance of ultrasound is influenced by the operator's experience and placental location (eg, posterior wall or low-lying placenta). Therefore, this study recommends combining MRI and ultrasound whenever feasible to maximize their respective advantages and improve diagnostic accuracy for invasive placental implantation.

Thinning of the uterine myometrium and an indistinct uterine myometrium-placenta interface are common imaging features of invasive placental implantation. This study found that the specificity of thinning of the uterine myometrium as an isolated diagnostic feature was relatively low (59.54%), which may be related to the physiological enlargement of the uterus and changes in the attachment site of the placenta in late pregnancy. Additionally, studies[17] have indicated that in pregnant women with a history of cesarean section, placental implantation usually occurs at the postoperative scar site. The heterogeneity of scar tissue may further increase the incidence of interface blurring. This result suggests that no single imaging feature can accurately predict the occurrence of invasive placental implantation; a comprehensive analysis incorporating multiple indicators is necessary. Low T2WI signal within the placenta and abnormal vascular proliferation are key MRI features. This study demonstrated that these features are not only significant for diagnosing invasive placental implantation but also hold independent value in predicting adverse clinical outcomes. Multivariate logistic regression analysis revealed high odds ratios for both features, further verifying their reliability as critical diagnostic indicators. Low T2WI signal within the placenta and abnormal vascular proliferation often reflect abnormal blood supply states between the placenta and uterus, and their distribution and morphology are closely related to the depth of placental invasion.[18,19] However, individual differences in the presentation of placental and vascular abnormalities, along with the influence of imaging equipment resolution and reviewer experience, underscore the need for future quantitative studies using standardized imaging analysis tools.

Localized bulging of the placenta/uterus is another important imaging feature of invasive placental implantation, primarily characterized by local outward bulging of placental tissue invading the uterine myometrium and even penetrating the serosal layer.[20] This study found that the diagnostic sensitivity of localized bulging was relatively low (below 60%), likely because this feature is more common in cases of percreta. However, it has high specificity in assessing severe invasive placental implantation and can serve as a supplementary diagnostic indicator. Previous studies[21] have suggested that the mechanism of localized bulging may involve invasive placental villi expanding outward through localized defects in the uterine myometrium, accompanied by abnormal vascular formation. Since this feature often appears in more severe cases, identifying it on imaging requires a comprehensive assessment in conjunction with other invasive implantation features. The disappearance of the retroplacental space is another key imaging indicator, especially significant in ultrasound imaging. Related literature[22] has suggested that when the placenta invades the uterine myometrium, the normal interface between the placenta and the uterine wall is disrupted, leading to the disappearance of the retroplacental space. Imaging may even show the placenta directly contacting adjacent tissues or organs. This study showed that the disappearance of the retroplacental space has high sensitivity and specificity for diagnosing invasive placental implantation, particularly in cases of concurrent placenta previa, making it a valuable feature for screening invasive implantation. Therefore, it is recommended to include retroplacental space assessment as a priority in routine ultrasound examinations to provide more evidence for early detection of invasive placental implantation.

Moth-eaten changes within the placenta are a highly specific imaging feature of invasive placental implantation, mainly characterized by disordered internal placental signals, irregular defects, and imaging abnormalities caused by placental villi invading the uterine myometrium.[23,24] This study showed that the specificity of moth-eaten changes in diagnosis reached 91.91%, and their specificity in predicting adverse outcomes was 90.17%, highlighting their importance in diagnosing invasive placental implantation. The pathological basis of moth-eaten changes may involve deep invasion of placental villi into the uterine myometrium, causing localized tissue destruction and blood flow disorders.[25] These pathological changes result in irregular low-signal areas within the placenta, which are characteristically displayed as moth-eaten defects on MRI. Previous studies[26] have also identified moth-eaten changes as a significant marker of invasive placental implantation, providing critical references for clinical diagnosis and surgical risk assessment. Based on the findings of this study, moth-eaten changes should be considered a core imaging feature for diagnosing invasive placental implantation, particularly in severe or complex cases, where they can significantly improve diagnostic precision and reliability. The ultrasound scoring system, which integrates features such as the disappearance of the retroplacental space, moth-eaten changes within the placenta, and disordered blood flow at the placental base, offers a quantitative diagnostic tool. In this study, an ultrasound score ≥3 was considered an effective criterion for determining invasive placental implantation, improving the diagnostic efficiency of ultrasound to some extent. However, as the scoring system may still be influenced by operator subjectivity, further optimization of scoring standards and exploration of automated evaluation technologies are needed to reduce human error.

The results of this study further emphasize that MRI and ultrasound each provide distinct and complementary diagnostic information in invasive placental implantation. MRI is superior in demonstrating placental internal architecture and causes of interface disruption, while ultrasound offers real-time assessment of placental location and blood flow. More importantly, by integrating these features into a combined diagnostic model, we achieved significantly higher diagnostic accuracy (AUC = 0.932) compared with single modalities, underscoring the incremental value of feature integration. Such findings are consistent with previous studies that highlighted the complementary value of MRI and ultrasound in evaluating placenta accreta spectrum disorders.[27,28] In high-risk obstetric settings—particularly in patients with prior cesarean section or suspected placenta percreta—the joint application of MRI and ultrasound may provide the most reliable basis for early intervention and surgical planning. This integrative strategy therefore has substantial implications for refining diagnostic workflows and guiding individualized peripartum management. In addition, future work should continue to explore multimodal imaging integration, such as combining MRI and ultrasound data for algorithm-based analysis, applying artificial intelligence for automated feature recognition, and developing standardized scoring systems that minimize subjectivity.

Nevertheless, this study has several limitations: its retrospective single-center design may introduce selection bias, and the lack of external validation limits generalizability. Observer subjectivity in imaging interpretation, despite good interobserver agreement, also remains a concern. Future multicenter prospective studies with larger cohorts and standardized imaging protocols are needed to confirm the robustness of our findings. Despite these limitations, this study demonstrates that integrating MRI and ultrasound features into a predictive model can substantially improve diagnostic performance, laying an evidence-based foundation for optimizing invasive placental implantation diagnosis and management strategies.

## Conclusion

This study demonstrates that integrating MRI and ultrasound imaging features into a combined diagnostic model significantly improves the diagnostic accuracy of invasive placental implantation (AUC = 0.932) and shows high value in predicting adverse intraoperative outcomes (AUC = 0.941). The combined model exhibits incremental advantages in identifying key imaging features, such as thinning of the myometrium, low T2 signal within the placenta, focal bulging of the placenta/uterus, and disrupted blood flow at the placental base, overcoming the limitations of single imaging modalities. These findings suggest that in high-risk obstetric patients—particularly those with prior cesarean section or suspected placenta percreta—the joint application of MRI and ultrasound can provide a reliable basis for early intervention and surgical planning.

Although this study is limited by its retrospective single-center design, small sample size, and lack of external validation, good interobserver agreement supports the reproducibility and clinical applicability of the combined diagnostic approach. Future multicenter prospective studies incorporating standardized imaging protocols and automated analytic algorithms are warranted to further confirm the robustness and generalizability of the combined model, providing evidence-based guidance for clinical management of invasive placental implantation.

## Disclosure

The authors declare that there are no conflicts of interest that could have influenced the interpretation or publication of the results.

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