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US and MR imaging findings to detect placental adhesion spectrum (PAS) in patients with placenta previa: a comparative systematic study

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Abstract

Purpose To compare the performance US and MR in identifying placental adhesion spectrum (PAS) in placenta previa (PP) and to establish a potential method of image interpretation.

Methods US and MR examinations of 51 patients with PP were selected. The presence of imaging signs commonly used to detect PAS was assessed. Penalized logistic regression was performed considering histology as standard of reference; only signs statistically significant ($p < 0.05$) were considered for ROC and multivariate analysis. The probability of PAS according to the presence of US and/or MR signs was then assessed.

Results At univariate analysis, loss of retroplacental clear space, myometrial thinning (MT) and placenta lacunar spaces on US, intraplacental dark bands (IDBs), focal interruption of myometrial border (FIMB) and abnormal vascularity (AV) on MR were statistically significant ($p < 0.01$). Three diagnostic methods for PAS were then developed for both US and MR when at least one (Method 1), two (Method 2) or three (Method 3) imaging signs occurred, respectively. Method 2 for MR showed a significantly ($p < 0.05$) higher accuracy (91%) compared to the other methods. When MR IDBs and AV as well as IDBs and FIMB were present in combination with US MT the probability of PAS increased from 75 to 90% and from 80 to 91%, respectively.

Conclusion MR demonstrated a higher diagnostic accuracy than US to detect PAS. However, since the combination of MR and US signs could improve the probability to detect PAS, a complementary diagnostic role of these techniques could be considered.

Keywords Ultrasound (US) · Magnetic resonance imaging (MRI) · Placenta previa · Placental adhesion spectrum (PAS) · Diagnostic accuracy

Introduction

Placenta adhesion spectrum (PAS) refers to an abnormal placentation consisting in chorionic villi invading the myometrium through a defect of the decidua basalis. Based on the depth of myometrial invasion, three types of PAS are described: placenta accreta when chorionic villi are attached to the myometrium rather than being within the decidua basalis; placenta increta when the placenta invades the myometrium; and placenta percreta when the placenta invades beyond or through the myometrium [1]. One of the major causes of PAS is the presence of a placenta previa (PP) abnormally implanted in the lower uterine segment within 2 cm from internal cervical os (marginal PP) or completely covering it (complete PP) in a patient with a history of previous cesarean section (CS) that lead to the presence of a

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scar within myometrium fibers; in particular, the presence of PAS does not allow the detachment of the placenta from the myometrium during the delivery determining a high risk of hemorrhage and often requiring hysterectomy [2].

Therefore, the detection of PAS during pregnancy appears crucial to guarantee the appropriate clinical and surgical management; in this setting, ultrasound (US) is the first-level imaging modality to identify placenta previa and to assess the risk of PAS, being proved to have an overall good diagnostic accuracy [3]. However, limitations of US are mainly related to a posterior placental location, patient's habitus and operator-dependence. Magnetic resonance (MR) is reported as a useful imaging technique to assess PAS when US findings are inconclusive or in case of posterior placental location. When compared to US, MR showed a comparable diagnostic accuracy in detecting PAS in PP patients [4–9]. In this setting, discrepancies between US and MR imaging have been reported in previous studies [10–13] and particularly the role and usefulness of MR over US are still debated [14]. The diagnosis of PAS using these two imaging modalities is based on the detection of suggestive US and MR imaging signs [15], but how to use them for imaging interpretation is currently under investigation.

The aim of this study was to systematically compare the performance of US and MR imaging signs in identifying PAS in patients with PP and to establish a potential method of image interpretation for both modalities.

Methods

Patient population

This retrospective study was approved by the local institutional review board and written informed consent was waived. All pregnant patients with complete PP who underwent US followed by MR examination for suspicion of PAS at our institutions from January 2012 and June 2018 were selected. Inclusion criteria were the following: > 18-year-old pregnant patients with PP who underwent both US and MR examinations within the same week and for whom the histological proof of PAS after cesarean section was available. Exclusion criteria were: patients for whom US or MR images were not retrieved on incomplete for the retrospective evaluation; MR examinations significantly affected by mother/fetal motion artifacts or prematurely interrupted by the patients due to claustrophobia; patients for whom the histological proof was not available.

US acquisition

Transabdominal and transvaginal US examinations were performed by an obstetrician trained in placenta sonographic assessment, using a GE Healthcare Voluson E8 (GE Healthcare, Milwaukee, WI) US machine with a 5-MHz convex probe and a 7-MHz transvaginal convex probe. On b-mode examination placental location, its internal structure as well as relationship with neighboring organs were evaluated; color-Doppler US examination integrated by pulse wave spectral-Doppler was performed to assess blood flow at the level of suspected placental lacunae identified at b-mode evaluation. Images were systematically collected and stored along with videos of the relevant findings in order to be suitable for a retrospective evaluation.

MR acquisition

MRI was performed using a 1.5 T scanner (Gyroscan, Intera, Philips, Best, The Netherlands) with a phased-array body coil. The following MR sequences were acquired: Single-shot Turbo-Spin-Echo (TSE) T2-weighted sequence (FOV 405 × 321 mm, matrix: 232 × 164, slice thickness 5–6 mm, number of slice 40, Flip angle: 90°, GAP 1, TR/TE = 381/80 ms) in the three acquisition planes (axial, sagittal and coronal); breath-holding was requested to minimize respiratory motion artifact; and Thrive Spectral Attenuated Inversion Recovery (SPAIR) T1-weighted sequence (FOV: 395 × 280 × 340 mm, matrix: 192 × 192, slice thickness 4 mm, number of slice 60, Flip angle: 10°, GAP 2, TR/TE = 3.6/1.7 ms). No fetal sedation was used. No intravenous contrast agent injection was administrated. Written informed consent for MRI study was obtained from all patients. Total MR scanning duration time was around 20 min.

Imaging analysis

On US images, the presence of the following imaging signs commonly used to detect PAS [16–19] was assessed in consensus by two obstetricians trained in placenta sonographic assessment (L.S. and R.E.), both blinded to clinical history and pathological diagnosis: (1) Abnormal placental lacunae, defined as numerous, large and irregular lacunae (Finberg grade 3) showing high velocity blood flow at color-Doppler evaluation; (2) myometrial thinning, < 1 mm or undetectable; (3) placental bulge, consisting of a deviation of the uterine serosa away from the expected plane, due to placental bulge into a neighboring organ, typically the bladder; (4) loss of the clear space underneath the placental bed; (5) focal exophytic mass, intended as the presence of placental tissue seen breaking through the uterine serosa and extending beyond it; and (6) bladder wall interruption, defined as loss or interruption of the hyperechoic band between the uterine serosa and the bladder wall. In case of disagreement, a third obstetrician with 30 years of experience (P.M.) was consulted. MR images were analyzed in consensus by two radiologists (P.P.M. and V.R.) with fifteen and 8 years of

experience in genitourinary MRI, both blinded to clinical history and pathological diagnosis. The presence of the following MR signs suggestive of PAS was assessed, as previously reported [15, 20]: (1) intraplacental dark bands, consisting of nodular or linear areas of low signal intensity on T2-weighted images; (2) focal interruption of myometrial border with loss of the trilaminate structure; (3) abnormal vascularity, consisting of tortuous and enlarged flow voids on T2-weighted sequence deep within placental tissue and/or at the level of the uterine serosa; (4) uterine bulging as loss of normal "pear shape" of the uterus; (5) tenting of the bladder as pinched and stretched contour wall; and (6) direct visualization of adjacent tissues invasion. In case of disagreement, a third radiologist with 20 years of experience (S.M.) was consulted.

Statistical analysis

Penalized maximum likelihood logistic regression [21] was performed in order to identify US and/or MR imaging signs independently associated to PAS, considering histology as standard of reference. Only imaging signs statistically significant ($p < 0.05$) at univariate analysis were considered for multivariate analysis as well as to define diagnostic criteria of methods for imaging analysis. Sensitivity, specificity, positive and negative predictive values were calculated using standard formula. Receiver operating characteristic curve (ROC) analysis was used to calculate the area under the curve (AUC) [22]. Furthermore, the probability of PAS of the defined diagnostic criteria of imaging analysis was calculated [23]. Statistical analysis was performed using Stata 15.1 software (StataCorp, College Station, TX). A p value < 0.05 was considered significant.

Results

Based on our inclusion and exclusion criteria, 51 pregnant patients (mean age 35 years, range 20–45 years, mean gestational age 35 weeks) with complete PP who underwent both US and MR examinations were selected. In detail, we excluded patients with incomplete or not retrieved US images ($n = 4$), patients with MRI images affected by mother/fetal motion MR artifacts ($n = 2$) and patients for whom histological proof was unavailable ($n = 3$). Clinical and histological data of patient population are reported in Table 1. The location of placenta previa was anterior ($n = 24$), posterior ($n = 15$), antero-posterior ($n = 10$) or lateral ($n = 2$) on both US and MR images. A total of 23 cases of PAS was observed of which 15 (65%) placenta accreta, 4 (17.5%) placenta increta and 4 (17.5%) placenta percreta; in particular, the occurrence of PAS according to placental locations was the following: anterior ($n = 10$), posterior ($n = 7$) and antero-posterior ($n = 6$). Of note, patients with PAS were from 29 to 40 years old. The remaining 28 patients were free of PAS.

Results of the univariate analysis are reported in Table 2; only loss of retroplacental clear space, smallest myometrial thickness and placenta lacunar spaces on US as well as intraplacental dark bands, focal interruption of myometrial border and abnormal vascularity on MR were statistically significant ($p < 0.01$). Using these significant imaging signs, three diagnostic methods to detect PAS were developed for both US and MR, respectively; specifically, the presence of at least one (Method 1), two (Method 2) or three (Method 3) significant imaging signs was considered as diagnostic criterion for PAS for each modality. AUC, sensitivity, specificity, positive and negative predictive values of the three Methods for US and MRI are reported in Table 3. In particular, the presence of at least two of the significant MR signs (Method 2-MR) showed the highest accuracy with an AUC value of 91%. Among US Methods, the presence of at least two significant US signs (Method 2-US) showed the highest diagnostic accuracy (75%), but significantly lower as compared to Method 2-MR ($p = 0.028$); this difference was due to a greater number of false positive cases recorded by US ($n = 9$) as compared to MR ($n = 3$) as well as a greater number of false negative cases obtained by US ($n = 4$) as compared to MR ($n = 1$); the comparison of ROC curves for Method 2 by both MR and US is illustrated in Fig. 1. At multivariate analysis including both US and MR signs significant at univariate analysis, only intraplacental dark bands at MR ($p = 0.002$) was independently associated to PAS (Table 4); of note, this imaging sign was present in all true positive MR cases ($n = 22$) in combination with abnormal vascularity ($n = 18$) and focal interruption of myometrial border ($n = 14$). Figures from 2 to 5 illustrate several correlative examples of MR and US findings of which two concordant cases (Figs. 2 and 3) as well as two discordant cases (Figs. 4 and 5). Probability values of PAS for MR Method 2 are reported in Table 5; in particular, the combinations of intraplacental dark bands with abnormal vascularity as well as with focal interruption of myometrial border showed the highest probability of PAS, respectively, 75% and 80%; conversely, when abnormal vascularity and focal interruption of myometrial border were present in absence of intraplacental dark bands the probability of PAS was lower (28%). In addition, when MR intraplacental dark bands and abnormal vascularity as well as MR intraplacental dark bands and focal interruption of myometrial border were present in combination with US myometrial thinning the probability of PAS increased from 75 to 90% and from 80 to 91%, respectively. Similarly, when US myometrial thinning was present in combination with MR focal interruption of myometrial border and abnormal vascularity the probability of PAS increased from 28 to 47%.

Table 1 Clinical features of patient population

Patient	Age	GA (weeks) at US and MR examinations	Gravidity	CS	Placental location US = RM	Histology
#1	32	30	III	2	Antero-posterior	ACC
#2	34	37	III	2	Posterior	INC
#3	41	38	VIII	3	Anterior	NEG
#4	29	35	II	1	Lateral	NEG
#5	38	35	III	3	Anterior	NEG
#6	31	36	I	1	Anterior	ACC
#7	29	36	II	1	Anterior	NEG
#8	41	36	II	0	Posterior	NEG
#9	35	37	IV	1	Posterior	NEG
#10	30	35	II	1	Antero-posterior	NEG
#11	42	37	III	2	Posterior	NEG
#12	30	37	III	2	Antero-posterior	PER
#13	40	35	III	1	Antero-posterior	PER
#14	42	34	III	2	Antero-posterior	NEG
#15	40	35	I	0	Posterior	NEG
#16	34	37	II	1	Anterior	ACC
#17	33	38	II	1	Antero-posterior	INC
#18	30	37	II	1	Anterior	NEG
#19	37	38	III	1	Anterior	INC
#20	37	30	IV	2	Anterior	NEG
#21	31	32	III	2	Anterior	NEG
#22	33	35	II	0	Anterior	NEG
#23	29	36	II	2	Anterior	ACC
#24	34	37	II	1	Antero-posterior	ACC
#25	38	34	II	1	Lateral	NEG
#26	35	37	IV	0	Anterior	NEG
#27	45	35	III	1	Anterior	NEG
#28	38	33	II	1	Posterior	NEG
#29	42	36	II	1	Antero-posterior	NEG
#30	37	32	III	1	Anterior	NEG
#31	37	37	XII	3	Posterior	INC
#32	37	37	IV	1	Anterior	PER
#33	27	37	II	1	Posterior	ACC
#34	33	34	II	1	Antero-posterior	ACC
#35	27	36	II	0	Anterior	ACC
#36	31	30	III	2	Posterior	NEG
#37	40	32	II	1	Anterior	ACC
#38	29	33	IV	2	Anterior	NEG
#39	40	34	VIII	1	Posterior	ACC
#40	39	36	II	1	Posterior	NEG
#41	39	35	III	2	Anterior	NEG
#42	41	36	III	1	Anterior	ACC
#43	36	32	VI	3	Anterior	ACC
#44	38	30	III	2	Anterior	NEG
#45	28	35	II	1	Anterior	NEG
#46	40	34	V	1	Posterior	NEG
#47	37	34	VI	1	Antero-posterior	NEG
#48	32	35	III	2	Posterior	ACC
#49	31	36	IV	3	Posterior	ACC
#50	36	33	II	1	Posterior	PER
#51	33	36	II	0	Anterior	ACC

GA gestational age, *CS* cesarean section, *US* ultrasound, *MR* magnetic resonance, *ACC* placenta accreta, *INC* placenta increta, *PER* placenta percreta, *NEG* negative for Placental Adhesion Spectrum

Table 2 Results of the univariate analysis for US and MR signs

Imaging sign		Odds ratio	95% CI[a]	*p* Value
US	Abnormal placental lacunae	2.724	1.333–14.779	0.015*
	Myometrial thinning	5.962	2.659–32.655	0.000*
	Placental bulge	1.392	0.524–7.796	0.306
	Loss of the clear space	6.166	2.296–34.585	0.002*
	Focal exophytic mass	1.590	0.32–10.130	0.500
	Bladder line interruption	1.493	0.671–8.175	0.182
MR	Intraplacental bark band	80.604	11.800–565.161	0.000*
	Focal interruption of myometrial border	4.967	2.233–27.185	0.001*
	Abnormal vascularity	3.155	1.529–17.133	0.008*
	Uterine bulging	2.285	0.26–17.433	0.480
	Tenting of the bladder	14.980	0.476–198.830	0.139
	Adjacent tissue invasion	0.646	0.015–10.036	0.570

US ultrasound, *MR* magnetic resonance, *CI* confidence interval

[a]The confidence intervals of odds ratio are quite wide for all variables due to a small study population and in particular to a small number of cases

*Significant p value < 0.05

Table 3 Comparison of the diagnostic accuracy among the three imaging Methods for US and MR

	US			MR		
	Method 1	Method 2	Method 3	Method 1	Method 2	Method 3
Sensitivity (%)	91	83	65	100	96	41
Specificity (%)	46	68	82	46	89	96
PPV (%)	58	68	75	61	88	90
NPV (%)	87	83	74	100	96	68
AUC (%)	69	75	74	73	91*	70

Imaging methods consisted of the presence of at least one (Method 1), two (Method 2) or three (Method 3) significant imaging signs for US and MR

US ultrasound, *MR* magnetic resonance, *PPV* positive predictive value, *NPV* negative predictive value, *AUC* area under the ROC curve

*Significant p value (< 0.05) versus Method 1 and 3 of MR and versus Method 2 of US

Discussion

According to our experience, MR showed a diagnostic accuracy significantly higher as compared to US in detecting PAS in patients with PP. In particular, the presence of at least two MR signs (Method 2) showed the best diagnostic accuracy in identifying PAS; of note, the same method on US demonstrated a poorer performance. In detail, MR signs significantly associated to PAS were intraplacental dark bands, focal interruption of myometrial border and abnormal vascularity; similarly, US signs significantly associated to PAS were placental lacunae, myometrial thinning and loss of the retroplacental clear space. Among the three MR signs significantly associated to PAS, intraplacental dark bands was the best MR sign in predicting such abnormality. Furthermore, when on the basis of MR Method 2 intraplacental dark bands and abnormal vascularity as well as intraplacental dark bands and focal interruption of myometrial border were present in combination with US myometrial thinning, the probability of PAS increased from 75 to 90% and from 80 to 91%, respectively; thus, a complementary diagnostic role of these techniques could be considered. The incidence of PAS is progressively increasing due to the greater recourse to CS; in particular, the early detection of PAS is of crucial importance for patient management and US is the most widely imaging technique employed to detect PAS in patients with PP, often performed by gynecologists [2]. Diagnosis of PAS on US imaging is performed through the identification of several suggestive signs and recently different scores have been proposed to predict PAS: the placenta accreta index (PAI) and the Marsoosi's score [24, 25]. Both scores also include clinical data such as the number of previous cesarean delivery (≥ 2) along with US signs and placental location. US signs considered as

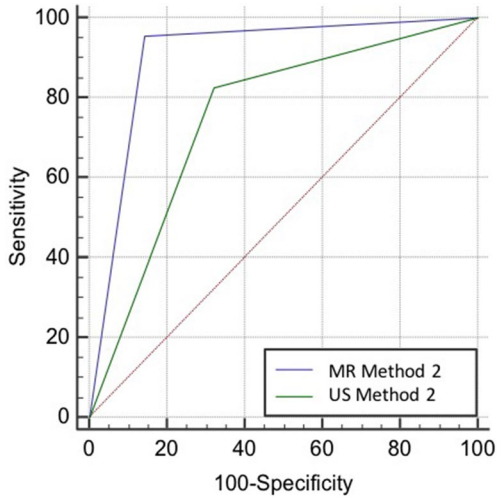

Fig. 1 Comparison of ROC curves according to Method 2 by both MR and US studies. MR Method 2 showed an AUC value significantly higher ($p = 0.0028$) as compared to US Method 2 (91 vs. 75%, respectively)

suggestive of PAS are placental lacunae, sagittal smallest myometrial thickness and bridging vessels for PAI index, while placental lacunae, loss of the retroplacental clear space and increased utero-placental vascularity are included in the score by Marsoosi et al. However, regarding the diagnostic accuracy of US in detecting PAS, some discrepancies among data currently reported in the literature still exist. Even if the majority of papers available reports an overall good performance of US [26], previous studies demonstrated low diagnostic accuracy values of US, similar to those found in our study [12]. These latter findings as well as the known limits of US such as the operator dependence and the difficulties in evaluating overweight patients and cases of posterior placental location, suggest a complementary role of MR in evaluating patients with PP and clinical suspicion of PAS. Recently, the presence of at least two abnormal MR signs has been reported as accurate to detect PAS [13, 20, 23]. The improvement of MR in terms of diagnostic accuracy to

Table 4 Results of the multivariate analysis for US and MR signs

Imaging sign		Odds ratio	95% CI[a]	*p* Value
US	Abnormal placental lacunae	1.013	0.079–12.882	0.992
	Myometrial thinning	5.689	0.587–55.125	0.133
	Loss of the clear space	0.790	0.060–10.278	0.585
MR	Intraplacental dark band	25.817	3.213–207.392	0.002*
	Focal interruption of myometrial border	2.577	0.340–19.490	0.359
	Abnormal vascularity	2.180	0.285–16.674	0.453

US ultrasound, *MR* magnetic resonance, *CI* confidence interval

[a]The confidence intervals of odds ratio are quite wide for all variables due to a small study population and in particular to a small number of cases

*Significant p value < 0.05

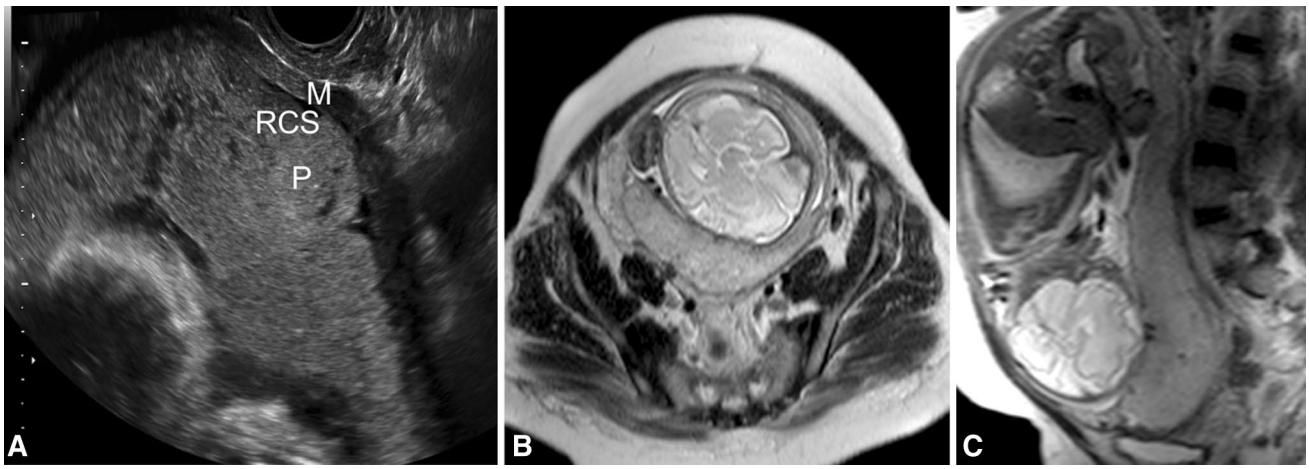

Fig. 2 True negative for PAS on both US and MR imaging. **a** Transvaginal B-mode US transverse image; MR TSE T2-weighted MR images acquired on axial **b** and coronal **c** plane. In **a**, a homogeneous placenta (P) is appreciable with preserved retroplacental clear space (RCS) and regular myometrial (M) thickness. MR also demonstrated a homogeneous placenta (**b** and **c**) with no detectable signs suggestive of PAS

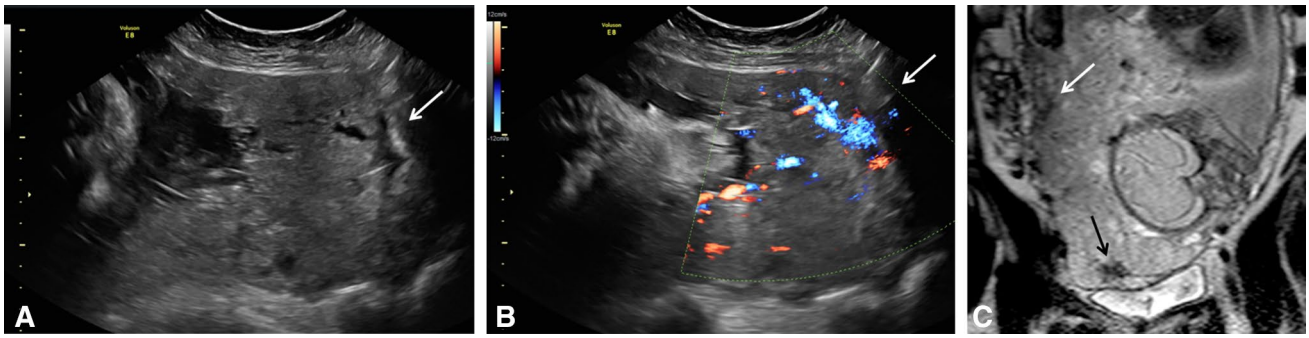

Fig. 3 True positive for placenta accreta on both US and MR imaging. Transabdominal B-mode transverse (**a**) and color-Doppler (**b**) US images; **c** MR TSE T2-weighted MR images acquired on coronal plane. Intraplacental lacunae (white arrow in **a**), hypervascularized at color-Doppler (**b**) are detectable at US examination. MR (**c**) confirmed the presence of intraplacental dark bands (black arrow) and the interruption of myometrial border (white arrow)

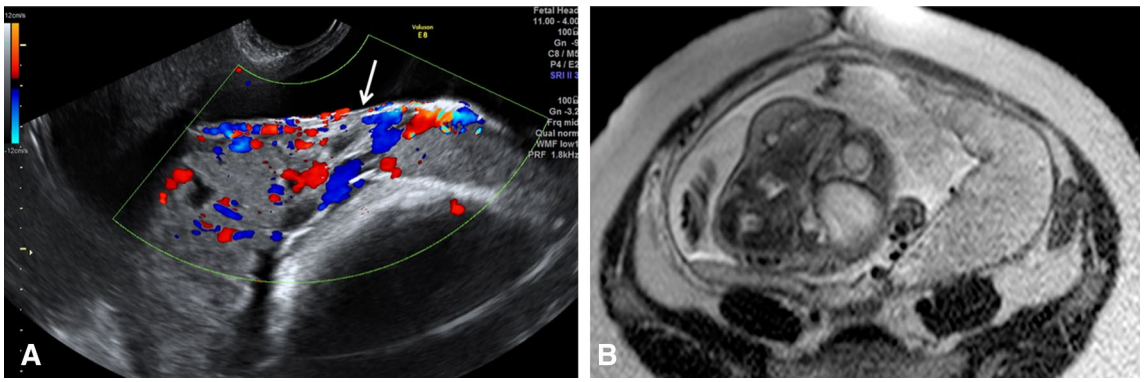

Fig. 4 False positive of PAS on US imaging. **a** Transvaginal Color-Doppler US transverse image; **b** MR TSE T2-weighted image acquired on axial plane. In **a**, hypervascularized placental lacunae (white arrow) are detectable. No MR signs suggestive of PAS were found on MR images (**b** and **c**)

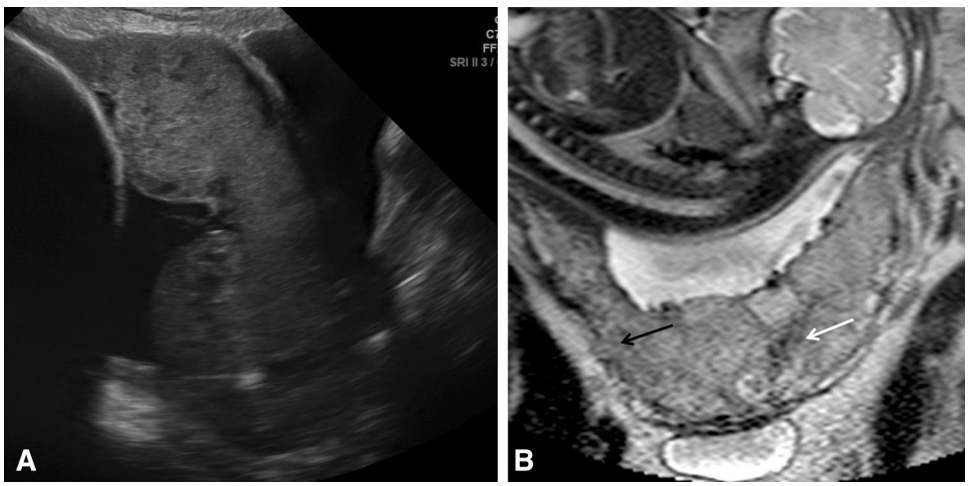

Fig. 5 False negative of placenta accreta on US imaging. **a** Transabdominal B-mode US transverse image; **b** MR TSE T2-weighted image acquired on axial plane. No signs suggestive of PAS were found at US imaging. MR images (**b**) revealed the presence of intraplacental dark band (white arrow) and focal interruption of myometrial border (black arrow)

detect PAS is probably related to the increasing clinical role of this technique and related imaging reporting expertise in detecting specific MR signs [15]. Previous studies have compared the diagnostic accuracy of US and MR in predicting PAS. In particular, a recent meta-analysis including eighteen comparative studies showed that the two modalities have a similar predictive diagnostic accuracy [4]. However, some discrepancies in terms of

Table 5 Probability values of PAS according to MR Method 2 and MR Method 2 integrated by US-MT

Probability of PAS for possible combinations of MR signs according to MR Method 2 and MR Method 2 integrated by US-MT				
	Value	Standard error	*p* Value	95% CI
MR Method 2				
MR-IDBs MR-AV	**0.75**	0.720	0.654	0.195–9.908
MR-IDBs MR-FIMB	**0.80**	0.779	0.652	0.134–0.956
MR-AV MR-FIMB	0.28	0.820	0.555	0.007–0.753
MR Method 2 integrated by US-MT				
MR-IDBs MR-AV US-MT	**0.900**	0.831	0.542	0.280–0.995
MR-IDBs MR-FIMB US-MT	**0.912**	0.864	0.551	0.216–0.997
MR-AV MR-FIMB US-MT	0.470	0.863	0.719	0.034–0.955

In bold, probability values of MR-IDBs/AV and MR-IDBs/FIMB that increased when US-MT was also detected on US images

IDBs intraplacental dark bands, *AV* abnormal vascularity, *FIMB* focal interruption of myometrial border, *MT* myometrial thinning, *CI* confidence interval, *PAS* placental adhesion spectrum, *MR* magnetic resonance, *US* ultrasound

diagnostic accuracy between US and MR have been reported with the first showing higher or lower values as compared to MRI [10–13]. Although the availability of comparative studies between US and MR as well as the variety of imaging signs, no systematic studies have been conducted to provide a methodology on how to use US and MR signs to interpret the corresponding images. In the present study, we assessed the presence of US and MR signs reported in the literature as suggestive of PAS in a population of patients with PP; in particular, US and MR signs significantly associated to PAS were identified using the univariate analysis. US signs significantly associated to PAS were loss of the retroplacental clear space, myometrial thinning and placental lacunae. MR signs significantly associated to PAS were intraplacental dark bands, focal interruption of myometrial border and abnormal vascularity. Subsequently, three diagnostic methods for each modality were used and then directly compared, consisting of the presence of at least one, two or three signs, respectively. For US, among the three proposed methods, Method 2 performed better than Methods 1 and 3, but the difference was not statistically significant. For MR, among the three proposed methods, Method 2 performed significantly better than Methods 1 and 3. However, the diagnostic accuracy of Method 2 using MR was significantly higher as compared to Method 2 of US in identifying PAS; in details, this difference was due to a greater number of false positive or negative cases obtained by US as compared to MR; of note, the occurrence of false positive or negative cases in US and MR imaging has been reported in patients with PP [28, 29]. Among US and MR signs, only MR intraplacental dark bands were independently associated to PAS at multivariate analysis; indeed, this sign was found in the majority (96%) of patients with PAS at histology. This finding is concordant with previous studies in which the presence of intraplacental dark bands represents the most significant MR sign to detect PAS, as originally suggested by Lax et al. [30] and also successively confirmed [31]. Similarly, abnormal vascularity and focal interruption of myometrial border, which were significantly associated to PAS in our experience, are also reported as useful MR signs to detect PAS [15]. In our case series, the combination of abnormal vascularity and intraplacental dark bands was observed in the majority (82%) of true positive cases using Method 2, while the combination of focal interruption of myometrial border and intraplacental dark bands was observed in 64% of true positive cases using Method 2; in this regard, the association of at least two MR signs has been previously suggested as a reliable method to detect PAS [13, 20, 27, 32]. In addition, imaging findings were analyzed in terms of probability to detect PAS on the basis of possible combinations of MR imaging signs using Method 2. According to our data, the combinations of two MR signs showing the highest probability of PAS were represented by intraplacental dark bands along with abnormal vascularity or focal interruption of myometrial border; conversely, when focal interruption of myometrial border and abnormal vascularity were associated, without the occurrence of intraplacental dark bands, the probability of PAS was lower. Moreover, when US myometrial thinning was also present in combination with MR intraplacental dark bands and abnormal vascularity as well as with MR intraplacental dark bands and focal interruption of myometrial border an increase in terms of probability of PAS was obtained. However, when US myometrial thinning was also present in combination with MR focal interruption of myometrial border and abnormal vascularity the increase in terms of probability of PAS was less relevant. The reason to explain this difference in terms of increase of probability of PAS combining US and MR signs seems to be related to the presence of intraplacental dark bands on MR; indeed, this imaging sign was the only independent predictor of PAS at multivariate analysis. Therefore, an integrated analysis of US and MR imaging signs might be proposed; in this regard, a combined scoring system using US and MR has

been recently reported [33]. The strength of this study is represented by the comparison between US and MR in assessing PAS through the detection of a panel of imaging findings to identify specific diagnostic criteria, including the possibility to combine US and MR findings to increase the probability of PAS. On the other hand, the first limitation of this study is due to the small sample size of our patient population that strongly warrants the confirmation of our results on a larger cohort of patients; moreover, the limited number of placenta percreta in our case series might have influenced the significance of US and MR signs typically suggestive of placenta percreta (i.e., bladder wall interruption on US and tenting of the bladder as well as adjacent tissue invasion on MR) at univariate analysis; the last limitation is represented by the retrospective nature of our investigation. In conclusion, the results of our study suggest a better diagnostic accuracy of MR over US to detect PAS in patients with PP; in particular, the association of at least two MR or US signs indicative of PAS represents the most accurate method of imaging analysis for both modalities. The best MR sign to detect PAS was the presence of intraplacental dark bands, alternatively associated with focal interruption of myometrial border or abnormalvascularity. However, despite its lower diagnostic accuracy, US still remains the first level imaging modality considering the wide availability and patient comfort. Furthermore, the combination of MR and US signs could significantly improve the probability of PAS. Thus, a complementary diagnostic role of these imaging techniques might be considered in the routine clinical practice.

Compliance with ethical standards

Ethical approval All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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