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MAGNETIC RESONANCE

Society of Abdominal Radiology (SAR) and European Society of Urogenital Radiology (ESUR) joint consensus statement for MR imaging of placenta accreta spectrum disorders

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Abstract

Objectives This study was conducted in order to establish the joint Society of Abdominal Radiology (SAR) and European Society of Urogenital Radiology (ESUR) guidelines on placenta accreta spectrum (PAS) disorders and propose strategies to standardize image acquisition, interpretation, and reporting for this condition with MRI.

Methods The published evidence-based data and the opinion of experts were combined using the RAND–UCLA Appropriateness Method and formed the basis for these consensus guidelines. The responses of the experts to questions regarding the details of patient preparation, MRI protocol, image interpretation, and reporting were collected, analyzed, and classified as "recommended" versus "not recommended" (if at least 80% consensus among experts) or uncertain (if less than 80% consensus among experts).

Results Consensus regarding image acquisition, interpretation, and reporting was determined using the RAND–UCLA Appropriateness Method. The use of a tailored MRI protocol and standardized report was recommended.

Conclusions A standardized imaging protocol and reporting system ensures recognition of the salient features of PAS disorders. These consensus recommendations should be used as a guide for the evaluation of PAS disorders with MRI.

Key Points

- *MRI is a powerful adjunct to ultrasound and provides valuable information on the topography and depth of placental invasion.*
- *Consensus statement proposed a common lexicon to allow for uniformity in MRI acquisition, interpretation, and reporting of PAS disorders.*
- *Seven MRI features, namely intraplacental dark T2 bands, uterine/placental bulge, loss of low T2 retroplacental line, myometrial thinning/disruption, bladder wall interruption, focal exophytic placental mass, and abnormal vasculature of the placental bed, reached consensus and are categorized as "recommended" for diagnosing PAS disorders.*

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Abbreviations

ACR	American College of Radiology
BGE	Balanced gradient echo
DOR	Diagnostic odds ratio
DWI	Diffusion-weighted imaging
ECR	European Congress of Radiology
ESGAR	European Society of Gastrointestinal and Abdominal Radiology
ESUR	European Society of Urogenital Radiology
FIGO	International Federation of Gynecology and Obstetrics
HASTE	Half Fourier single-shot turbo spin echo
IVF	In vitro fertilization
NLR	Negative likelihood ratio
NPV	Negative predictive value
PAS	Placenta accreta spectrum
PIWG	Placental Imaging Working Group
PLR	Positive likelihood ratio
PPV	Positive predictive value
SAR	Society of Abdominal Radiology
SSFSE	Single-shot fast spin echo
SSH-TSE	Single-shot turbo spin echo
UFSE	Ultra-fast spin echo
UOC DFP	Uterine and Ovarian Cancer Disease-Focused Panel

Introduction

Placenta accreta spectrum (PAS) represents the abnormal invasion of the placental chorionic villi beyond the decidua basalis. The placental villi invade into varying depths of the decidua and underlying myometrium giving rise to placenta accreta, increta, and percreta. The annual incidence of invasive placentation is estimated to be 1 in 300 pregnancies and is projected to be over 9000/year by 2020 [1, 2]. There has been a 10-fold increase in the incidence of this entity over the last 50 years, mostly attributed to increasing number of Cesarean sections and advanced maternal age and will expectedly increase over time [3].

In the presence of placenta previa, the history of one Cesarean section confers a risk of almost 24% for PAS disorders [4]. This risk reaches up to 64% when there is a history of multiple (≥ 3) Cesarean sections [5, 6]. Prior Cesarean section, placenta previa, advanced maternal age, high gravidity and parity, multiple abortions with curettage, and anterior low location of the placenta have all been established as risk factors for placenta accreta [7]. PAS is the leading cause of peripartum hysterectomy, performed in up to 64% of women with this condition [5, 6]. Peri- and postpartum hemorrhage may be uncontrollable leading to maternal mortality rates up to 7% [8]. These rates are even higher when bladder invasion is present [8]. A considerable body of literature states that accurate identification of PAS disorders prenatally allows obstetricians to avoid unexpected findings during surgery, schedule an appropriate multidisciplinary approach, and subsequently optimize maternal and neonatal care [9–12].

Recent times have seen a notable increase in published literature on this topic. The International Federation of Gynecology and Obstetrics (FIGO) recently published a five-article series on the management of PAS disorders [10–14]. This disorder has been addressed with multiple terms in the literature including morbidly adherent placenta, abnormally invasive placenta, and placenta accreta spectrum disorder. Utilizing the term PAS disorders seems to be most favored and was adopted for this manuscript [15]. Just like the heterogeneity of nomenclature, the imaging techniques and reporting of imaging findings of PAS disorders remain variable and nonuniform [16]. Ultrasound remains the first line of imaging for detection of PAS disorders; however, tertiary centers are also using MRI for preoperative diagnosis and surgical planning. Uniform ultrasound [17] and MRI [16] lexicon has been proposed. Given the critical clinical and research applications of imaging, there is an immediate need to establish a relatively uniform technique, lexicon for describing findings, and structured reporting. This would allow for robust uniform reporting to obstetricians and gynecologic oncology surgeons, when they receive an MRI report from a radiologist.

The purpose of this work was to establish a joint SAR/ESUR guidelines on PAS disorders and standardize MRI acquisition, interpretation, and reporting.

Methods

Member recruitment and data sheet creation

The SAR Uterine and Ovarian Cancer Disease-Focused Panel was established in March 2014 to disseminate knowledge and improve the quality of imaging techniques utilized for imaging gynecologic oncologic processes, aiming to improve the care of these patients.

The Placental Imaging Subgroup was created including members with expertise and interest in placental imaging. The chairs of this group contacted placental imaging experts from ESUR, and a placental working group was convened to prepare a consensus statement for MRI of PAS disorders.

We chose the RAND–UCLA Appropriateness Method (RAM) because of its strength in combining evidence-

Table 1 Results of imaging experts survey and literature review summary

Magnetic resonance imaging finding	Definition	Accuracy based on expert opinion
T2-dark bands	One or more areas of hypointensity on T2-weighted images, which are usually linear in configuration and often contact the maternal surface of the placenta	90% (95% CI 65–93%)
Placental bulge	Deviation of the uterine serosa from the expected plane caused by abnormal bulge of placental tissue toward adjacent organs, typically toward the bladder and parametrium. The uterine serosa may be intact, but the outline shape is distorted	100% (95% CI 92–100%)
Loss of T2 hypointense interface	Loss of a thin dark line behind the placental bed, as seen on T2-weighted images	90% (95% CI 84–96%)
Myometrial thinning	Thinning of the myometrium over the placenta to less than 1 mm or even invisible	90% (95% CI 87–95%)
Bladder wall interruption	Irregularity or disruption of the normal hypointense bladder wall, which can be accompanied by blood products in the bladder lumen	100% (95% CI 97–100%)
Focal exophytic mass	Placental tissue seen protruding through the uterine wall and extending beyond it Most commonly seen inside at least partially filled urinary bladder and laterally into the parametrium	95% (95% CI 95–100%)
Abnormal vascularization of the placental bed	Prominent vessels in the placental bed with disruption of the uteroplacental interface. They may extend to the underlying myometrium to a variable degree, reaching up to the uterine serosa; and may be accompanied by extensive neovascularization around the bladder, uterus, and vagina	100% (95% CI 96–100%)
Placental heterogeneity	Heterogeneous signal within the placenta, which can be seen on both T1- and T2-weighted sequences	70% (95% CI 58–81%)
Asymmetric thickening/shape of the placenta	Part of the placenta, the portion involved with PAS and usually the part overlying the internal os (in cases of placenta previa) are asymmetrically thickened, compared to the rest of the placental tissue	50% (95% CI 39–61%)
Placental ischemic infarction	In the acute phase, areas of T2W hyperintensity and T1W hypointensity are present. Areas of asymmetric placental thinning are noted with chronic infarction	60% (95% CI 49–70%)
Abnormal intraplacental vascularity	Abnormal vessels, tortuous enlarged flow voids on T2-weighted images deep within the placenta	70% (95% CI 65–79%)

based data and expert judgments to attain consensus on a variety of clinically pertinent questions. RAM was previously used to develop the ESGAR consensus guidelines for MRI assessment of rectal cancer and ESUR guidelines on MRI in endometrial cancer [18, 19].

The study went through seven basic steps as follows:

– Step 1: Literature review

Medline (Ovid), EMBASE (embase.com), and the Cochrane Library were searched for original manuscripts published between 2007 and 2019 pertaining to MRI evaluation of PAS disorders. Multiple experts reviewed this literature to summarize imaging findings most commonly used to diagnose PAS disorders (Table 1). A core group of seven authors reviewed all the cited literature and the subtopic literature was reviewed by specific section reviewers.

– Step 2: Questionnaire development

A questionnaire consisting of 21 questions was developed by the lead author (G.M.) and later refined with input from two lead authors (P.J., L.P.), focusing on key technical requirements, protocol nomenclature, and description of the MRI signs [16]. A standardized terminology for MRI descriptors of PAS disorders was proposed for the evaluation of PAS disorders.

– Step 3: Panel selection

Expert panel comprised of all members of the SAR–ESUR Placental Imaging Working Group.

– Step 4: Survey prior to the first meeting of the panel

The questionnaire was distributed to all panel members via electronic mail in December 2017, and responses were recorded.

– Step 5: Data extraction and analysis

Survey responses were collated in January 2018 and analyzed by the lead author (G.M.).

On the basis of survey answers, each item was classified as: (1) "recommended" (at least 80% agreement in favor), (2) "not recommended" (at least 80% agreement in opposition), or (3) "uncertain" (i.e., consensus was not reached, with less than 80% agreement). In March 2018, the results were presented to and discussed with the ESUR Female Pelvic Imaging Working Group at the Annual ECR Meeting and with the SAR Working Group at the Annual SAR Meeting, respectively.

– Step 6: Second and final meeting of the panel

The members of the ESUR–SAR Placental Working Group met again at the Annual ESUR Meeting in September 2018 with two lead authors (G.M. and L.P.) serving as moderators. Final results were circulated among all panel members 2 weeks prior to this meeting and discussed in a face-to-face meeting during which a final consensus was reached.

– Step 7: Data reporting

The final result was ultimately classified as (1) "recommended" versus (2) "not recommended" or (3) "uncertain."

In two consensus meetings in 2019, a draft of the current update was developed and ultimately approved by all the subcommittee members.

Results

The final working group consisted of 21 radiologists: 11 from Europe (Austria, France, Greece, Italy, UK), 8 from the USA, 1 from Asia (Japan), and 1 from South America, all with known expertise in placental imaging. The panel's recommendations are summarized in Table 2. Consensus statement was prepared for imaging protocol, diagnostic features for MRI assessment, and structured reporting. The MRI signs included in the consensus statement are explained in detail below.

Hardware and patient preparation

The minimal recommended magnet field strength is 1.5 T; 3 T imaging can be performed based on institutional availability and protocols for imaging pregnant women. Per ACR MR safety guidelines, pregnant women can be imaged safely with field strengths of 3 T or less, using a normal-level specific absorption rate mode (< 2 W/kg). Currently, no deleterious effects on the exposed fetus (such as teratogenesis and/or acoustic damage) have been conclusively documented and MRI can be performed in any trimester of the pregnancy [20, 21]. Supine patient positioning, the use of pelvic phased-array coil, and moderately filled bladder are recommended. The use of intravenous gadolinium-based contrast agent is not required and the use of linear gadolinium-based contrast agents is not recommended [21]. Imaging is best performed at 28–32 weeks of gestational age [22].

Sequences and imaging planes

Multiplanar T2-weighted (T2W) sequences of the pelvis are acquired: two-dimensional T2W HASTE (half Fourier single-shot turbo spin echo) sequences in the sagittal, coronal, and axial planes through the uterus are mandatory to evaluate PAS disorders. This sequence is termed single-shot fast spin echo (SSFSE) on General Electric Healthcare scanners and single-shot turbo spin echo (SSH-TSE) or ultra-fast spin echo (UFSE) on Phillips Healthcare scanners. T2W sequence in the axial oblique plane should be obtained perpendicular to the placenta–myometrium interface. An acquisition slice thickness ≤ 4 mm is recommended. For the assessment of the topography of placental invasion, T2W nonfat-suppressed sequences are recommended. T1W TSE sequence with fat suppression, in the axial or sagittal plane, is recommended for detection of any intra- or retroplacental hemorrhage/abruption.

Table 2 Synopsis of expert consensus and key recommendations for magnetic resonance imaging prerequisites and technique (based on items for which ≥ 80% consensus was reached)

a. Hardware
– MRI should be performed with an external surface coil on a 1.5- or 3.0-T MRI system
b. Patient preparation
– The optimal time for performing MRI is between 28 and 32 weeks, next line. Supine patient positioning
– Patient with moderately filled bladder
– The use of intravenous gadolinium contrast agent is not required
c. Sequences and imaging planes
– Sagittal, coronal, and axial 2D T2W HASTE (half Fourier single-shot turbo spin echo)/SSFSE (single-shot fast spin echo) sequences through the uterus are mandatory to evaluate PAS disorders
– Axial oblique T2W sequence should be prescribed perpendicular to the placenta–myometrium interface
– The slice thickness ≤ 4 mm is recommended.
– T2-weighted fat-suppressed sequences are not recommended

Optional sequences

Multiplanar steady-state free procession (SSFP) sequences can be performed for distinction of vascularity and placental margins. Diffusion-weighted imaging (DWI) can be performed to aid in the delineation of the placental boundaries in patients with severely engorged myometrium, but literature is lacking evaluating DWI for PAS disorders. Recommendations for DWI include:

- Free-breathing technique (level of evidence, IV)
- Lower *b* values ranging from 0 or 50 s/mm^2 and upper *b* values ranging from 600 to 1000 s/mm^2 (level of evidence, IV)
- Slice thickness ≤ 5 mm (level of evidence, V)

Table 3 Sample magnetic resonance imaging protocol at 1.5 T

Parameter	Steady-state sequence		T2 half Fourier sequence		T1 3D sequence fat sat		DWI
	Axial	Coronal/sagittal	Axial	Coronal/sagittal	Sagittal	Axial	Axial/sagittal
Repetition time/echo time (ms)	3.31/1.36	3.51/1.41	800/85	800/87	4.27/1.56	4.35/1.61	3200/75
Flip angle (°)	60	60	120	120	10	10	10
Field of view (mm)	320–400	320–400	320–400	430	320–400	320–400	320–400
Matrix	256 × 192	320 × 270	320 × 216	384 × 256	256 × 256	256 × 192	256 × 192
Parallel imaging factor	2	2	2	2	3	2	2
Section thickness (mm)	4	4	4	4	3	3	5
Intersection gap (mm)	0.9–1	0	0.9–1	0	0	0	0
No. of sections per stack	35	20–24	35	20–24	40	72	
time per stack (s)	20–15	18–10	20–15	16	21–18	17	180
No. of stacks	2–3	1	2–3	1	1	2	1

Protocols for MR imaging at 1.5- and 3.0-T systems are summarized in Tables 3 and 4. Before publication, these protocols were approved by the SAR UOC Disease-Focused Panel. Structured reporting for PAS disorders is summarized in Table 5.

Imaging findings

MRI appearance of the normal placenta and myometrium

Normal appearance of the placenta and myometrium is provided as a diagrammatic representation in Fig. 1a.

MRI appearances of PAS disorders

The MRI findings suggestive of PAS disorders which reached consensus (Table 1) and are therefore categorized as "recommended" are as follows:

1. Dark intraplacental bands on T2W images

Dark intraplacental bands on T2W have irregular margins and a maximum diameter ranging from 6 to 20 mm or more (Figs. 1b and 2a, b). They are thought to represent areas of fibrin deposition due to repetitive intraplacental hemorrhage or infarcts [23–27].

Association between increasing volumes of abnormal intraplacental dark bands with the depth of placental invasion has been reported [28]. According to the results of a meta-analysis, the presence of abnormal intraplacental dark bands is the most sensitive MRI feature for the diagnosis of placenta accreta, increta, and percreta with corresponding values of 89.7, 89.7, and 82.6%; specificity, however, was only moderate with corresponding values of 49.5, 63.4, and 58.5% [29]. Furthermore, intraplacental dark bands have been shown to be a significant predictor of poor maternal outcome as they were

Table 4 Sample magnetic resonance imaging protocol at 3.0 T

Parameter	Single-shot fast spin echo (SSFSE)	LAVA-Flex or Dixon dual echo	Single-shot fast spine echo (SSFSE) (nonpropeller)	Diffusion-weighted imaging (DWI, optional)	T2 fast spin echo (nonpropeller, optional)
	Axial/coronal/sagittal	Axial/center over the placenta	Coronal/high-resolution imaging (reduced field of view), center over the placenta	Axial and sagittal/center over the placenta	Axial and sagittal/center over the placenta
Repetition time/echo time (ms)	2000/100	4.2/1.2	2000/100	5000/30.5	4000/120 (axial) 11,000/74 (sagittal)
Flip angle (°)	–	15	–		120 (axial)
Number of excitations	–	1	–	2	2
Section thickness/skip (mm)	4/0	3/0	4/0	6/0	4/0
Matrix	384 × 256	260 × 256	384 × 256	80 × 80	320 × 256
Field of view (mm)	360	340	260–280	340	240
Phase	Right to left	Anterior to posterior	Right to left		Right to left
Oversample	PE FOV 1.0	PE FOV 1.1	PE FOV 1.0	PE FOV 1	No phase wrap

Table 5 Structured reporting for placenta accreta spectrum disorder

Clinical: key clinical information prior to MRI
– Patient age
– Gestational age
– Number of previous Cesarean sections
– Relevant ultrasound findings, if available
MRI
Presence of placenta previa
Location of the placenta
MRI: detect placental invasion
It is recommended to include the presence or absence of the following imaging findings in the imaging report:
1. T2-dark intraplacental bands
2. Placental/uterine bulge
3. Loss of retroplacental T2-hypointense line
4. Myometrial thinning
5. Bladder wall interruption
6. Focal exophytic mass
7. Abnormal vascularization of placental bed
8. Placental heterogeneity
9. Asymmetric shape/thickening of the placenta
10. Placental ischemic infarction
11. Abnormal intraplacental vascularity
MRI: suspected depth of placental invasion
Accreta or increta
Placenta percreta
MRI: topography of the placenta invasion
To determine the topography of the placenta invasion, a line is drawn perpendicularly to the middle of the posterior bladder wall, determining an upper area named S1, which mainly corresponds to the uterine body, and an area below this line, named S2, which involves the lower segment, cervix, and upper vagina
MRI evidence of extrauterine extension
Bladder invasion: location and structures involved
Parametrial invasion: location and structures involved

associated with increased intraoperative blood loss and hysterectomy [2].

2. Placental/uterine bulge

Abnormal uterine bulge leads to widening of the lower uterine segment with an hourglass configuration of the uterus, rather than the typical inverted pear shape, best delineated on coronal and/or sagittal images (Figs. 1c and 2c) [29–31]. This bulging of the uterine contour has been suggested as a useful sign in the assessment of myometrial invasion [24, 32–35] with a sensitivity and specificity for the diagnosis of placenta increta and percreta of 76.7 and 62.5%, respectively [29]. Where a bulge in the uterine contour is accompanied by focal disruption of the myometrium, the specificity of the sign increases [32]. Overall, abnormal bulging has excellent accuracy and is highly associated with the presence of placenta increta and percreta [35] (Figs. 1c and 2c).

3. Loss of retroplacental hypointense line on T2W images

Focal interruptions or loss of this interface can be observed in the areas of PAS disorders [33] (Figs. 1d and 2d). Loss of the dark uteroplacental interface in association with other signs such as myometrial thinning may increase the sensitivity for the diagnosis of PAS disorders [36]. Focal defects/myometrial thinning in the uteroplacental interface and disruption of the inner layer of the uteroplacental interface on T2W images can be predictive of PAS with high sensitivity (97.4%) but with poor specificity (36.4%) [37].

4. Myometrial thinning

Myometrial thinning has been described as an early sign suggesting placenta accreta [28, 31, 38, 39] (Figs. 1e and 2e). When the myometrium is well demonstrated, focal interruptions of the wall are seen at sites of invasion with placental tissue extending through the breach in case of percreta [25, 32, 40]. Focal interruption of the myometrium is a sensitive sign for detection of PAS disorders but conveys high interobserver variability when reader experience is taken into account [24, 25, 29, 32]. In a meta-analysis, focal myometrial interruption had a sensitivity of 63.6%, specificity of 72.2%, DOR of 3.53, PLR of 2.33, and NLR of 0.59 for identifying accreta [29]. The same values for diagnosing increta were 67.9%, 77.5%, 7.28, 3.02, and 0.41, respectively [29]. When diagnosing percreta, these values were 78.6%, 70.2%, 6.46, 2.42, and 0.42, respectively [29, 41]. In expert opinion, myometrial thinning may be present in normal placentas, but it is highly unlikely to display total loss or disruption of the T2W hypointense outer myometrial wall in the absence of PAS disorder. Because extreme thinning can occur in late gestation, this sign should not be used as an independent sign but used in conjunction with other signs of PAS disorder.

5. Bladder wall interruption

Invasion of the bladder may be suspected in case of interruption, irregularity, or "tenting" of the bladder wall [24, 33, 39, 40, 42, 43]. Direct visualization of placental tissue in the bladder lumen on MRI is highly specific (100%) for bladder involvement; however, this feature is observed only in a small number of patients with percreta [41] (Figs. 1f and 2f). The "bladder vessel sign," defined as visualization of numerous tortuous signal voids traversing the space from the uterus to

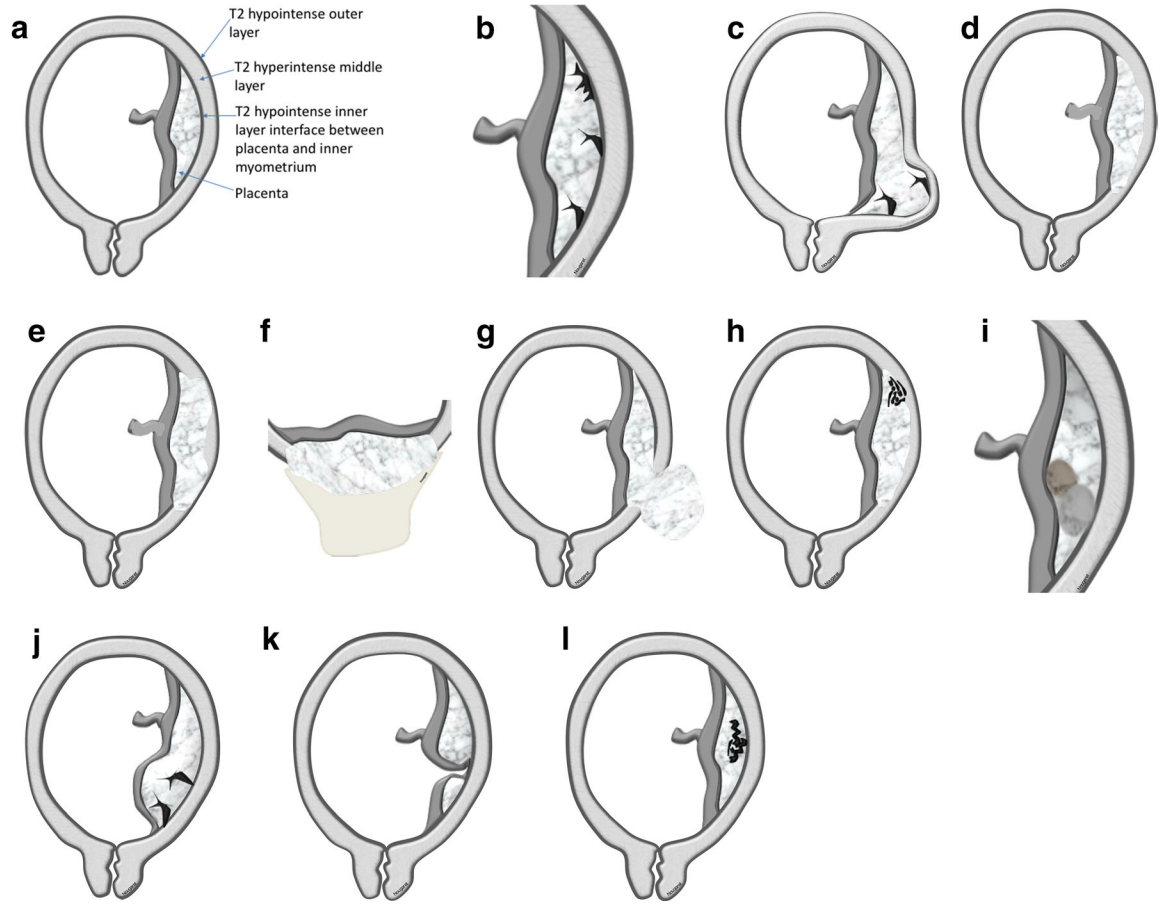

Fig. 1 Diagrammatic representation of magnetic resonance imaging features of normal placenta and myometrium and placenta accreta spectrum disorders. **a** Normal placenta demonstrating a preserved T2-hypointense layer at the placenta–inner myometrium interface. Stratified appearance of the myometrium with T2-hypointense inner and outer layers and hyperintense middle layer is demonstrated. The uterus is pear shaped narrowing inferiorly without any bulges. Normal placenta has a symmetric disc-like appearance with gradually tapering edges. **b** Diagrammatic representation of T2-dark bands seen as irregular linear T2-dark areas, often contacting the maternal surface of the placenta. **c** Placental bulge is evidenced by deviation of the uterine serosa from the expected plane caused by abnormal bulge of placental tissue. This is usually accompanied by myometrial thinning over the region of the bulge. **d** Diagrammatic representation of loss of well-defined T2-hypointense placental–inner myometrial interface. **e** Diagrammatic representation of myometrial thinning, when the myometrium over the placenta may be thinned to less than 1 mm or even becomes invisible. Myometrial thinning can be of variable thickness in the region of placental implantation. **f** Diagrammatic representation of bladder wall interruption with placenta invading the bladder dome. The invasion can extend to the detrusor muscle and even deeper toward the bladder mucosa. **g** Diagrammatic representation of focal exophytic mass seen as placental tissue protruding through the uterine myometrium and extending beyond it. This is most commonly seen inside at least partially filled urinary bladder and laterally into the parametrium. **h** Diagrammatic representation of subplacental hypervascularity/abnormal vascularization of the placental bed demonstrated by prominent vessels in the placental bed with disruption of the uteroplacental interface. They may extend from the underlying myometrium to a variable degree, reaching up to the uterine serosa, and may be accompanied by extensive neovascularization around the bladder, uterus, and vagina. **i** Diagrammatic representation of heterogeneous placenta shown as altered background parenchymal signal. This heterogeneity is in addition to the T2-dark bands and abnormal intraplacental vascularity. **j** Diagrammatic representation of asymmetric thickening/shape of the placenta, which is thickened in the area affected by placenta accreta spectrum (PAS) disorder. Other features such as T2-dark bands co-exist in the region of thickening in cases of PAS disorders. **k** Diagrammatic representation of placental ischemic infarction: Normal placenta has uniform thickness with smooth tapering toward the edges without deep areas of tissue loss. Abnormal placenta affected by PAS disorder is abnormally thinned with focal loss of placental tissue in the area of infarction. **l** Diagrammatic representation of abnormal intraplacental vascularity: normal placenta on the left does not demonstrate large intraplacental flow voids. Tortuous enlarged flow voids on T2-weighted images deep within the placenta are present with placenta accreta spectrum disorder. Vessels present deep in the placenta are very unusual, especially when further away from the placental cord insertion

the bladder, seems to be another accurate predictor of bladder wall involvement (including bladder serosa) with high diagnostic indices up to 96% (Fig. 2g) [41]. Tenting of the bladder dome toward the uterine surface is another indicator of possible bladder wall invasion.

6. Focal exophytic mass

The presence of a focal exophytic mass is highly specific for PAS disorders and depicts placenta percreta and usually is located anteriorly toward the bladder or laterally toward

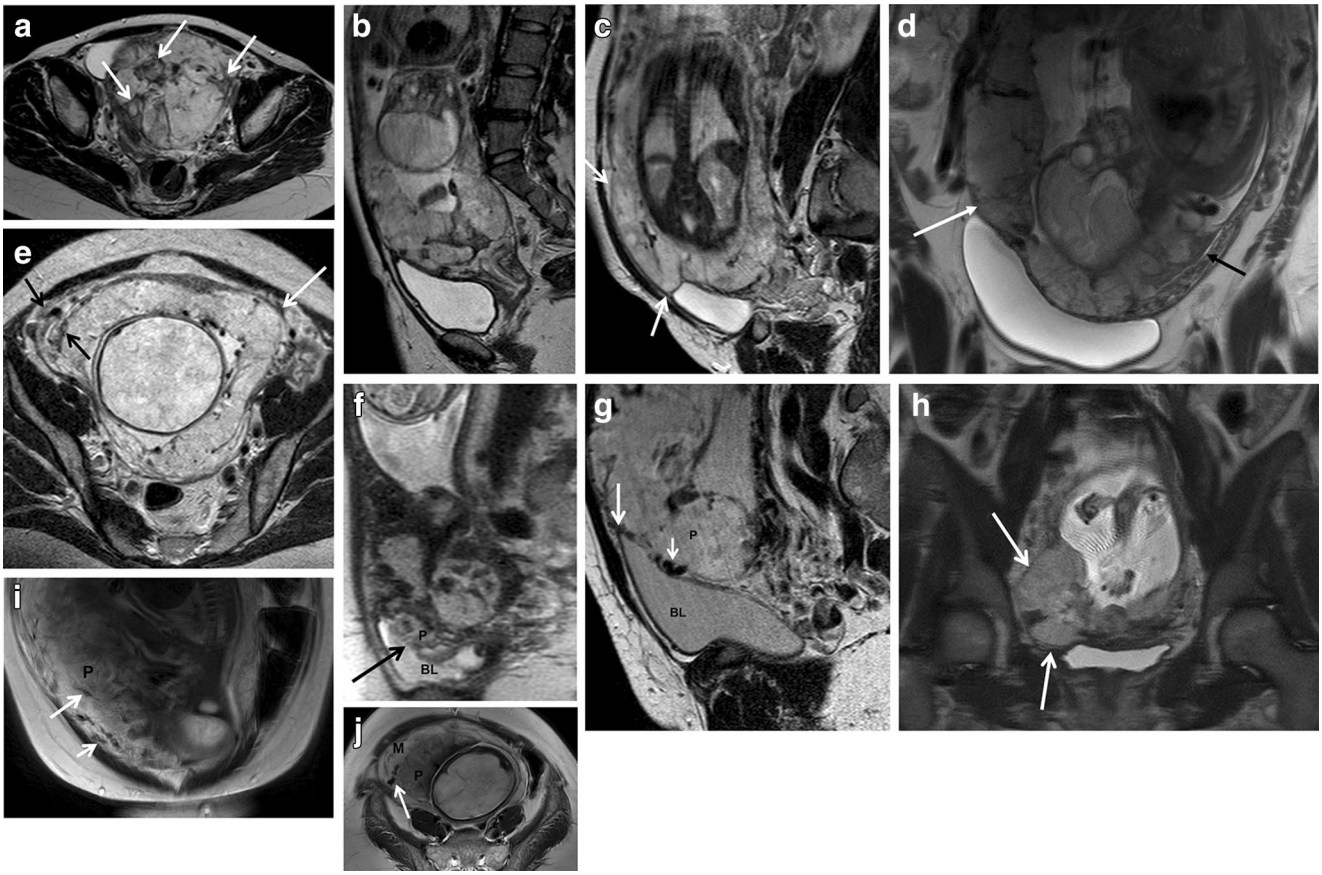

Fig. 2 Magnetic resonance imaging features of placenta accreta spectrum disorder, which reached consensus and are recommended by the expert group. All the images are from T2-weighted nonfat-suppressed sequences. **a**, **b** T2-dark bands (arrows) are defined as one or more areas of hypointensity on T2-weighted images, which are usually linear in configuration and often contact the maternal surface of the placenta. As shown in this example, multiple T2-dark bands can exist in the placenta and can contact the fetal surface in severe cases as well. Other imaging features of placenta accreta spectrum disorders including heterogeneous placenta and placenta previa are also present. **c** Placental bulge is defined as deviation of the uterine serosa from the expected plane caused by abnormal bulge of placental tissue (arrows) toward adjacent organs, typically toward the bladder and parametrium. The uterine serosa may be intact, but the outline shape is distorted. Overall, the placenta is heterogeneous with T2-dark bands and abnormal vascularity. **d** Loss of T2 hypointense interface is defined as the loss of a thin dark line behind the placental bed (white arrow), as seen on T2-weighted images. Normal T2-hypointense placental–myometrial interface is seen on the left (black arrow). **e** Myometrial thinning is defined as thinning of the myometrium over the placenta to less than 1 mm or even invisible (white arrow). On the left, there is loss of the uteroplacental interface with preservation of the low T2 outer myometrium/uterine serosa (white arrow). On the right, a normal sandwich-like appearance of the myometrium (black arrows) is seen with multiple flow voids present in the myometrium. **f** Bladder wall interruption is seen as irregularity and disruption (arrow) of the normal hypointense bladder (BL) wall, with placental tissue protruding into the bladder lumen. This can be accompanied by blood products in the bladder lumen. **g** Bladder involvement can also be evidenced by large flow voids (short arrow) in the bladder wall. In this example, bladder tenting (long arrow) is also present, which is associated with bladder invasion. **h** Focal exophytic mass is defined as placental tissue seen protruding through the uterine wall and extending beyond it (arrows). In this case, the placenta is focally protruding toward the parametrium and has a mass-like appearance. While most commonly seen inside at least partially filled urinary bladder, this appearance can be seen extending laterally into the parametrium as well. **i**, **j** Subplacental hypervascularity/abnormal vascularization of the placental bed is characterized by prominent vessels (arrow) in the placental bed with disruption of the uteroplacental interface. They may extent to the underlying myometrium to a variable degree, reaching up to the uterine serosa (short arrow), and may be accompanied by extensive neovascularization around the bladder, uterus, and vagina (M = myometrium, P = placenta)

the parametrium (Figs. 1g and 2h) [29, 31, 44–46]. Therefore, when considered for overall detection of PAS disorders, this finding has a low sensitivity, being absent in placenta accreta or increta [29, 31, 44–46]. A meta-analysis showed that the presence of an exophytic placental mass along with bladder tenting was highly associated with placenta percreta [29].

7. Abnormal vascularization of placental bed

Placental bed constitutes the decidua and adjacent myometrium underlying the placenta [47]. In case of abnormal placentation, the vascular architecture at the placental bed exhibits major alterations, with the vessels becoming nonuniformly distributed and very heterogeneous

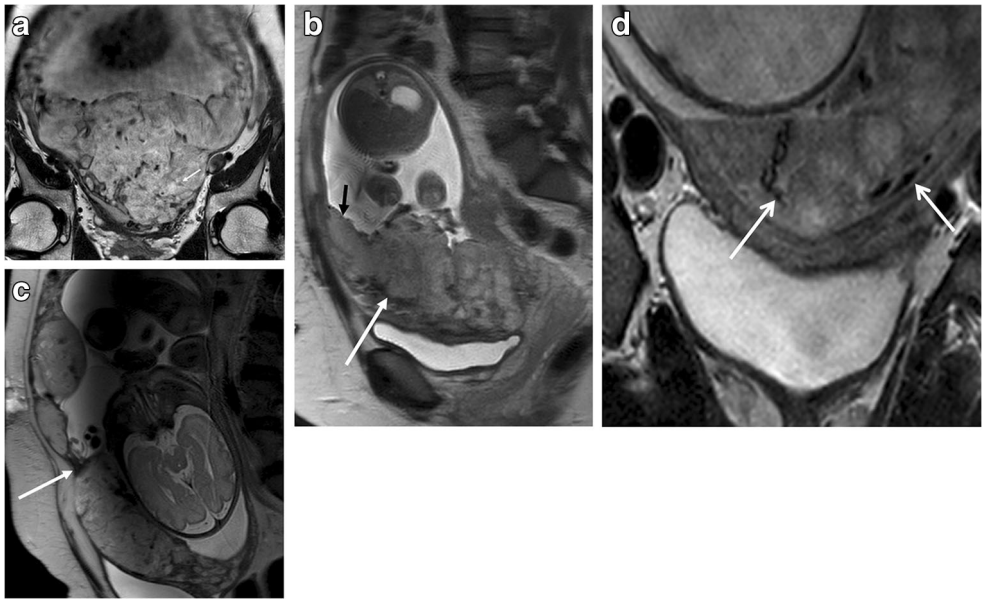

Fig. 3 Magnetic resonance imaging features of placenta accreta spectrum disorder, which did not reach consensus and are not recommended by the expert group. All the images are from T2-weighted nonfat-suppressed sequences. **a** Heterogeneous placenta is defined as heterogeneous signal within the placenta, which can be seen on both T1- and T2-weighted sequences. Although the presence of T2-dark bands (arrow) and abnormal intraplacental vascularity contributes to the overall heterogeneity, the placental tissue excluding these structures also appears heterogeneous with PASD. **b** Asymmetric thickening/shape of the placenta is defined as asymmetrical thickening of the placenta (white arrow), where it is involved with placenta accreta spectrum disorder, compared to the rest of the placental tissue (black arrow). It usually is the part overlying the internal os (in cases of placenta previa). The thickened portion also appears more heterogeneous compared to the rest of the placenta. **c** Placental ischemic infarction is seen as areas of asymmetric placental thinning (arrow) with chronic infarction. A small portion of thinned placenta is still present at this location, hence excluding the possibility of succenturiate lobe. **d** Abnormal intraplacental vascularity is the presence of abnormal vessels and tortuous enlarged flow voids (arrows), best on T2-weighted images deep within the placenta

in size [48]. The more aggressive the placentation, the more pronounced are the uteroplacental vascular changes [49]. Identification of this feature on MRI exhibited the greatest accuracy (AUC 0.91, $p < 0.001$) for the diagnosis of PAS with sensitivity, specificity, PPV, and NPV equal to 81.6, 100.0, 100.0, and 61.1%, respectively [41]. Also, this feature has demonstrated substantial interobserver agreement and proved to be a significant prognostic factor for the discrimination between placenta percreta and accreta/increta with an AUC equal to 0.76 ($p < 0.001$) and sensitivity, specificity, PPV, and NPV up to 80, 73.1, 59, and 88.3%, respectively [50]. The presence of uterine serosal hypervascularity on prenatal MRI is associated with increased intraoperative blood loss [50] as well as with other complications during delivery including hysterectomy or need for bladder repair [51]. In addition, extensive flow-void network extending from the uterine serosa to the vesicouterine space ("bladder vessel" sign) or within the parametrial adipose tissue ("parametrial vessel" sign) is a highly accurate feature for the diagnosis of bladder (Figs. 1h and 2i, j) (AUC 0.96, $p < 0.001$) and parametrial (AUC 0.80, $p < 0.003$) involvement in patients with PAS [41].

The findings for which consensus was not achieved are as follows and are categorized as "uncertain" (Table 1):

1. Placental heterogeneity (Figs. 1i and 3a)
2. Asymmetric shape/thickening of the placenta (Figs. 1j and 3b)
3. Placental ischemic infarction (Figs. 1k and 3c)
4. Abnormal intraplacental vascularity (Figs. 1l and 3d)

Although the above signs have been documented as predictors of PAS disorders, the expert consensus did not achieve the threshold for recommended. The reason this happened likely relates to the subjective nature of some of these findings and interreader variability. Additionally, some of these findings can be seen with expected evolution of the placenta with advancing gestation adding further to the confounding nature of these findings.

Management of placenta accreta spectrum disorder: impact of MR imaging

Intraoperative and postsurgical outcomes of patients with PAS disorders are directly related to the depth and topography of placental invasion, with cases affected by placenta percreta or showing parametrial invasion being at higher risk of morbidity [29, 52]. Therefore, prenatal identification between different degrees of placental myometrial extension is important as it

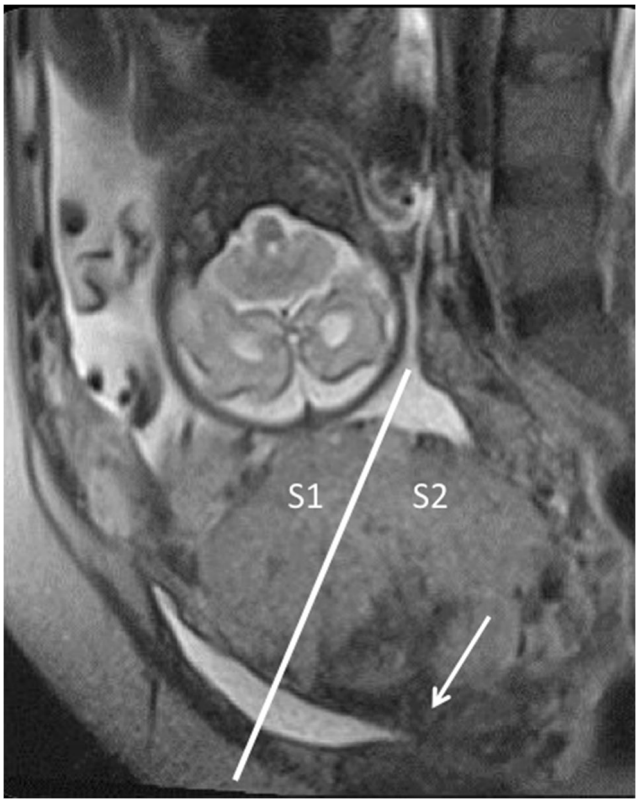

Fig. 4 Sagittal T2-weighted MRI shows the perpendicular plane dividing the posterior bladder wall into S1 and S2 areas. A line that perpendicularly crosses the middle of the posterior bladder wall determines an upper area named S1, which mainly corresponds to the uterine body, and an area below this line, named S2, which involves the lower segment, cervix, and upper vagina. White arrow shows the interrupted myometrium at the S2 area. Flow voids from abnormal vascularity are present at the myometrial–bladder interface. A practical anatomical landmark dividing uterine vascular zones is the peritoneal reflection, which determines area S1 (above the peritoneal reflection) and area S2 below the peritoneal reflection

assists clinicians to offer more careful counseling or implement individually tailored treatments (i.e., hysterectomy vs. more conservative surgery), improving the management of gravid patients affected with PAS.

Despite multiple studies, differentiating the three pathologic subtypes based on the presence or absence of myometrial invasion has been at best challenging. This is further confounded by the current lack of agreement in defining increta versus percreta by pathologists. Current FIGO guidelines recommend incorporating clinical grading during surgery with pathology [13]. Meta-analysis data by Familiari et al showed the excellent accuracy of MRI in identifying the depth and topography of invasion [29]. However, they do report a caveat that since all the patients who underwent MRI previously had suspicious ultrasound findings, these statistics may not represent the actual diagnostic performance of MRI. The topography of placental invasion can help indicate the most effective methods for proximal vascular control and appropriate targets for embolization/balloons based on institutional preferences [53]. A practical anatomical landmark dividing uterine vascular zones is the peritoneal reflection, which determines area S1 (above the peritoneal reflection, supplied by the uterine arteries) and area S2 (below the peritoneal reflection, supplied by the collaterals of the internal pudendal arteries). For S1 invasions, anterior internal iliac artery control is effective, but for S2 placental invasions, it is necessary to control the blood flow of the internal pudendal branches and their anastomotic connection, so the most accurate vascular control is the iliac common or aortic vascular control [54]. Identification of S1 and S2 areas can be established by MRI in the sagittal plane (Fig. 4). A line that perpendicularly crosses the middle of the posterior bladder wall determines an upper area named S1, which mainly corresponds to the uterine body and an area below this line, named S2, which involves the lower segment, cervix, and upper vagina. In most cases of PAS disorders with co-existing placenta previa, the placenta is located in S2 area, which also explained the high rate of failures with the use of uterine or internal iliac vascular control. MRI identified 100% of the cases with PAS with S1 and S2 invasion confirmed at surgery [29].

Conclusions

In conclusion, MRI is a powerful adjunct to ultrasound in the diagnosis of PAS disorders. Once the diagnosis is suspected on ultrasound, MRI can provide valuable information on the topography and depth of placental invasion in addition to the information readily available from ultrasound. This is particularly helpful in counseling the patients regarding their diagnosis and the potential effects on current pregnancy and future fertility. Surgical planning including the need for urological involvement and preprocedural planning for hemostasis and blood volume replacement can be achieved. One particular benefit of MRI is the reduced operator dependence as compared to ultrasound. However, the utilization and clinical application of MRI is heavily dependent on the expertise of the radiologists. By the means of this consensus statement, the authors intend to provide a common denomination to allow for uniformity in MR image acquisition, interpretation, and reporting lexicon. Given that MRI is noninvasive and radiation-free and has reduced operator dependence, it has the potential to serve as an important diagnostic tool. Uniformity of reporting will allow for improved research efforts and can be applied toward future clinical trials.

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Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Written informed consent was not required for this study because this is a consensus statement.

Ethical approval Institutional Review Board approval was not required as no patient information was accessed for this study.

Study subjects or cohorts overlap Some study subjects or cohorts have been previously reported in previous studies referenced in the manuscript.

Methodology
- Retrospective
- Observational
- Multicenter study

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