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Utility of diffusion-weighted MR imaging in the diagnosis of placenta accreta spectrum abnormality

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Abstract

Purpose: The aim of this study was to evaluate the utility of added DWI sequences as an adjunct to traditional MR imaging in the evaluation of abnormal placentation in patients with suspicion for placenta accreta spectrum abnormality or morbidly adherent placenta (MAP).
Materials and methods: The study was approved by local ethics committee. The subjects included pregnant women with prenatal MRI performed between July 2013 to July 2015. All imaging was performed on a Philips 1.5T MR scanner using pelvic phased-array coil. Only T2-weighted and diffusion-weighted imaging (DWI) series were compiled for review. Two randomized imaging sets were created: set 1 included T2-weighted series only (T2W); set 2 included T2W with DWI series together (T2W + DWI). Three radiologists, blinded to history and pathology, reviewed the imaging, with 2 weeks of time between the two image sets. Sensitivity, specificity, and overall accuracy for MAP were calculated and compared between T2W only and T2W + DWI reads. Associations between imaging findings and invasion on pathology were tested using the Chi-squared test. Confidence scores, inter-reader agreement, and systematic differences were documented.
Results: A total of 17 pregnant women were included in the study. 8 cases were pathologically diagnosed with MAP. There were no significant differences in the diagnostic accuracy between T2W and T2W + DWI in the diagnosis of MAP in terms of overall accuracy (62.7% for T2W vs. 68.6% for T2W + DWI, $p = 0.68$), sensitivity (70.8% for T2W vs. 95.8% for T2W + DWI, $p = 0.12$), and specificity (55.6% for T2W vs. 44.4% for T2W + DWI, $p = 0.49$). There was no significant difference in the diagnostic confidence between the review of T2W images alone and the T2W + DWI review (mean 7.3 ± 1.8 for T2W vs. 7.5 ± 1.8 for T2W + DWI, $p = 0.37$).
Conclusion: With the current imaging technique, addition of DWI sequence to the traditional T2W images cannot be shown to significantly increase the accuracy or reader confidence for diagnosis of placenta accreta spectrum abnormality. However, DWI does improve identification of abnormalities in the placental–myometrial interface.

Key words: Diffusion-weighted MR—DWI—Placenta accreta spectrum abnormality—Morbidly adherent placenta—MAP

Placenta accreta spectrum abnormality or morbidly adherent placenta (MAP) results from deficient endometrial deciduas basalis resulting in abnormal placental attachment to the uterine wall [1]. MAP refers to a spectrum of abnormal placentation: accreta, when placenta abnormally attaches directly onto the myometrium; increta, when placenta penetrates the myometrium; and percreta, when placenta completely

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invades through the myometrium, up to or beyond the uterine serosa. In its most severe form, MAP results in placental invasion into surrounding pelvic organs, most typically the bladder, abdominal organs, and occasionally the abdominal wall.

Prior Cesarean section (CS) delivery is the most common predisposing factor for development of MAP. The increasing rate of CS has led to increased incidence of MAP [1], with a previous CS shown to increase the rate of MAP in subsequent pregnancy by 8.7-fold [2]. Presence of placenta previa is another significant risk factor for MAP. The combination of placenta previa and history of 3 or more CS deliveries has been shown to raise the risk of MAP to 67% [3]. Additional risk factors include uterine anomalies, increasing maternal age, dilatation and curettage, and history of uterine surgery (including myomectomy) [4, 5].

The presence of MAP can portend catastrophic outcomes during and after surgery, including massive hemorrhage from hypertrophied abnormal placental–uterine vasculature, deep venous thrombosis, ureteral damage, sepsis, and disseminated intravascular coagulation [4]. The risks of maternal and fetal mortality are also high in the setting of MAP with 6–7% maternal and 9–19% fetal mortality reported in the literature [6–8]. MAP is the most common reason for emergent post-partum hysterectomy which carries its own serious co-morbidities (i.e., cystotomy, ureteral injury, and pulmonary embolism) [9]. Adequate multidisciplinary preparation has the potential to improve prognosis and decrease complications by coordinating staff (Obstetrics, Interventional Radiology, General Surgery, etc.), timing, and location of delivery (i.e., specialized/tertiary care center). Accurate prenatal diagnosis allows for detailed patient/family counseling, including discussions about future fertility and preparation for possible life-threatening obstetric complications [10].

Although ultrasound is the initial modality used to image the placenta, MRI has an important and expanding adjunct role in evaluating placental abnormalities, including MAP. MRI is particularly useful in evaluating MAP in the setting of posterior placenta and/or ambiguous US findings. Multiple MR criteria are considered helpful for the diagnosis of MAP including presence of placenta previa, bulging of uterine contour, placental signal heterogeneity, dark intraplacental bands (T2-weighted imaging), focal myometrial interruption or thinning, bladder tenting, and invasion of pelvic organs [9]. To assess these features, MRI protocols rely primarily on T2-weighted sequences. However, addition of diffusion-weighted imaging (DWI) has been proposed as a complementary sequence to evaluate for the presence and type of MAP [11]. Specifically, the inherent intensity difference between placenta (hyperintense) and myometrium (hypointense) on high B value sequences (> 400) may be useful in defining an abnormal placenta–myometrium interface [11].

Materials and methods

Study cohort

This study was approved by our Institutional Review Board. As a retrospective study, obtaining informed written consent was not required. Starting in July 2013, our institution began routinely including DWI sequences in all MRIs performed on pregnant patients. To accrue our cohort, we performed an initial database search on MRIs performed on pregnant women from July 2013 to July 2015 (using zVision software, Version 1.4.80 Build:5851 @ 2012 Clario Medical Imaging) and found 74 women with prenatal MRI performed for varied indications including known/suspected MAP (26 subjects), fetal anomalies (32 subjects), acute abdominal pain in pregnancy (15 subjects), and suspected maternal malignancy (1 subject). Of the 74 women, 17 subjects were included in our study after inclusion and exclusion criteria were applied. The inclusion criteria included complete visualization of the placenta and availability of pathologic placental review. The exclusion criteria included presence of significant fetal/maternal anomalies within the placental field-of-view, lack of pathologic placental review, and deliveries performed outside of our institution (resulting in lack of pathologic placental review). Of the 74 subjects, 47 women were delivered in our institution and 27 outside of our institution. Of those delivered at our institution, 21 had pathologic placental review (4 of which had either significant fetal/maternal anomalies in the field-of-view or incomplete visualization of the placenta, resulting in exclusion) leaving 17 women (Fig. 1). Medical chart review was performed by a single investigator blinded to the MR images and read results to document patient demographics and pathologic findings.

MR imaging protocol

All imaging was performed on a conventional 1.5T MR unit (Philips, Achieva, Netherlands) with patients imaged in the supine position using pelvic phased-array coil. Intravenous injection of gadolinium contrast agent was not used in any of the cases. FOV and imaging planes varied based on the indication: placenta accreta, fetal anomaly, abdominal pain in pregnancy, and suspected maternal malignancy. However, the T2W and DWI sequences were acquired with similar parameters in each patient.

Only T2-weighted and DWI/ADC series were compiled for review. Ultrafast T2-weighted Spin-Echo sequences (SSH-TSE) were acquired in at least 2 planes (FOV: 300 × 283, TE/TR: 90/921, slice thickness: 3 mm,

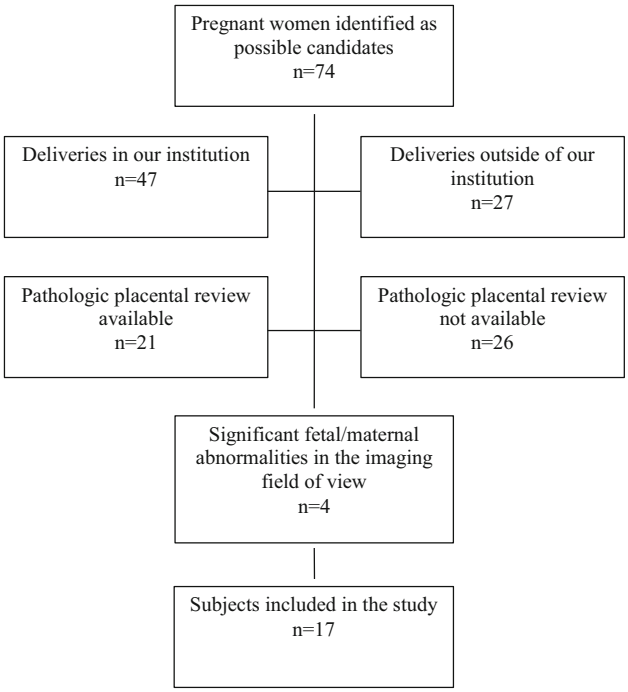

Fig. 1. Flowchart illustrating patient inclusion and exclusion criteria.

skip: 0.3) and all the multiplanar T2 sequences for placental evaluation were compiled for review. DWI sequences included high B value acquisition of B0, 50, 400, and/or 800 (FOV:380 × 330, TE/TR:65/5780, slice thickness:6 mm, skip:1) in axial plane and most included ADC maps: 14 subjects with B0, B400, B800; 2 subjects with B50, B400, B800, no ADC maps; 1 subject with B0, B50, B800 (B values in sec/mm^3). The ADC maps were compiled for review as well.

Image analysis

Two imaging sets were created: set 1 included T2-weighted series only (T2W); set 2 included T2W with DWI series together (T2W + DWI). Images in each set were de-identified and separately assigned random identifiers. Pathology reports were used as the reference standard to categorize each case as MAP present or absent and to further categorize the extent of placental invasion into accreta, increta, and percreta. Cases were then also randomized between image sets (i.e., patient 1 on set 1 was not the same as patient 1 on set 2). The images were then transferred to two CDs (one per image set; PC AutoPlay DICOM viewer included) for each reviewer.

Three fellowship-trained body radiologists with experience in interpreting prenatal MRI (between 4 and 8 years) reviewed the imaging. Two of the reviewers (readers 1 and 3) reported that DWI was done as routine in their institution for placental exams (reader 1: for 5 years; reader 3: for 1 year). Reviewers were blinded to history and pathology. The T2W CD was reviewed first. To avoid recall in the readers, the T2W + DWI CD was reviewed at least 2 weeks after completion of T2W CD. For each case, reviewers completed a digital questionnaire via REDCap (Research Electronic Data Capture). Questions were identical between the two image sets, except for an additional question for the T2W + DWI set (see Table 1). For both T2W and T2W + DWI reviews, radiologists were asked to evaluate placental morphology, presence or absence of MAP, degree of invasion (if present), and confidence in diagnosis. For T2W + DWI, reviewers were also asked if having DWI images available changed their suspicion or confidence in the presence of MAP (Table 1).

Statistical analysis

The unit of analysis was the patient and the read (three per patient for each of the T2W only and T2W + DWI reading sessions). For analysis of the reads, hypothesis tests were implemented as permutation tests with resampling performed by patient to account for the correlation between multiple reads of the same patient. Sensitivity, specificity, and overall accuracy for MAP were calculated for all readers combined and for each reader individually. These were compared between T2W only and T2W + DWI reads using the Sign test. Confidence scores were compared between T2W only and T2W + DWI reads using the Wilcoxon signed-rank test. The Chi-squared test was used to compare imaging findings and diagnoses between those with and without MAP by pathology.

Inter-reader agreement was summarized using Light's kappa (for 3 readers) and Cohen's kappa (for 2 readers) coefficients. To interpret kappa, ≤ 0.20 was considered poor agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and > 0.80 excellent agreement [12]. Kappa coefficients were compared between T2W and T2W + DWI reads using a permutation test. All statistical calculations were conducted with the statistical computing language R (version 3.1.1; R Foundation for Statistical Computing, Vienna, Austria). Throughout the analysis, two-sided tests were used, with statistical significance defined as $p < 0.05$ without adjustments for the number of comparisons.

Results

A total of 17 pregnant women were included in the study with the mean age of subjects being 31.1 years (range 18–39 years) and the mean gestational age at the time of imaging, 27 weeks 4 days (range 15 weeks 6 days–34 weeks 1 day). All pregnancies were singleton gestations. Of the 17 subjects, 14 subjects were evaluated for the presence of MAP, 2 subjects for the characterization

Table 1. Reader questionnaire

Type of question	Details
Are these features present or absent in the placenta?	1. Placenta previa 2. Heterogeneous signal intensity within the placenta 3. Increased and disorganized vascularity 4. Dark and thick intraplacental bands on T2-weighted image 5. Loss of retroplacental T2 dark zone 6. Uterine bulging 7. Tenting of bladder 8. Abnormal interface between placenta and myometrium If yes, which features are present: irregular margins, focal interruptions in myometrial wall, focal thinning, frank invasion, other (choose all that apply)
Open-ended	Describe any other features of placental–myometrial interface than those referenced above
Yes/no	Is MAP present? If yes, what is greatest level of invasion (accrete, increta, percreta; if increta and percreta present, choose percreta)?
Level of confidence in diagnosis	0–100%, in 10% increments (0–10%, 10–20%, etc.)
Added for T2W + DWI set: Relative to T2W images alone, did having the DWI/ADC images (Select one)	Increase level of suspicion for presence of MAP or increase level of confidence for presence of MAP Decrease level of suspicion for presence of MAP or increase level of confidence for absence of MAP Confounded interpretation, reducing level of confidence of presence or absence of MAP Did not change level of confidence for presence/absence of MAP

of isolated and small fetal anomalies (one with fetal chest mass and another with intracranial arachnoid cyst; the images provided for placenta evaluation in these subjects excluded any significant fetal anomaly to avoid bias), and 1 subject for abdominal pain (rule out appendicitis).

Among the 14 subjects being evaluated for MAP, all except 1 had a prior history of CS (mean number of prior CS: 2.1, range 0–4) and 7 had placenta previa in the current pregnancy. The patient without prior CS had a prior pregnancy complicated by profound post-partum hemorrhage with uterine atony, requiring Bakri balloon, and uterine artery embolization. Of the three patients being evaluated for other indications, none had CS delivery in prior pregnancies or placenta previa in the current pregnancy.

Delivery

For patients imaged to evaluate for MAP, all had CS delivery at an average gestational age of 32 weeks 3 days (range 16 weeks 4 days–36 weeks 5 days). Of these, 2 pre-viable fetuses were delivered: one at 16 weeks 4 days for uterine dehiscence with MAP present on pathology, and one at 21 weeks 3 days for intrauterine fetal demise (IUFD), with MAP absent on pathology.

For patients imaged for other indications, average gestational age at delivery was 40 weeks 1 day (range 39 weeks 2 days–40 weeks 5 days). Two had CS delivery (MR indication: intracranial arachnoid cyst and appendicitis, respectively) and 1 had vaginal delivery (MR indication: fetal chest mass).

Pathology, diagnostic performance, and confidence

In total, our cohort of 17 subjects had 8 cases with MAP present on pathology and 9 cases MAP absent on pathology. All cases of MAP were among the 14 patients imaged to evaluate for MAP. Diagnostic performance based on the T2W images alone and T2W + DWI images is summarized in Table 2. The accuracy for the diagnosis of MAP did not change significantly with the addition of the DWI sequence to the traditional T2WT2W sequence (62.7% vs. 68.6%, $p = 0.68$). Though the differences were not statistically significant, sensitivity for MAP tended to increase with the addition of the DWI sequence compared to the T2W images alone (70.8% vs. 95.8%, $p = 0.12$), while specificity tended to decrease (55.6% vs. 44.4%, $p = 0.49$). There was a similar pattern for each reader individually (Table 2).

Overall, by the 10-point confidence scale, there was no significant change in diagnostic confidence between the review of T2W images alone and the T2W + DWI review (mean: 7.3 ± 1.8 vs. 7.5 ± 1.8, $p = 0.37$). When analyzed by individual reader, reader 3 showed an apparent increase in confidence with the addition of DWI images (mean: 7.7 ± 1.5 vs. 8.7 ± 0.9, $p = 0.027$), while the other readers did not show significant changes (reader 1: 7.8 ± 1.2 vs. 7.9 ± 1.7, $p = 0.53$; reader 2: 6.3 ± 2.3 vs. 5.9 ± 1.7, $p = 0.41$).

Of the 8 cases with MAP present on pathology, readers 1, 2, and 3 reported that their level of suspicion for MAP increased with the addition of the DWI sequence to the T2W image in 8 (100%), 2 (25%), and 8 (100%) of cases, respectively (75.0% on average). Of the 9 cases MAP absent on pathology, the readers reported

Table 2. Diagnostic accuracy based on T2W images alone and T2W + DWI images

Readers	T2W Images			T2W + DWI Images		
	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity	Accuracy
All readers	70.8% (17/24)	55.6% (15/27)	63.7% (32/51)	95.8% (23/24)	44.4% (12/27)	68.6% (35/51)
Reader 1 only	62.5% (5/8)	55.6% (5/9)	58.8% (10/17)	100.0% (8/8)	44.4% (4/9)	70.6% (12/17)
Reader 2 only	75.0% (6/8)	55.6% (5/9)	64.7% (11/17)	87.5% (7/8)	33.3% (3/9)	58.8% (10/17)
Reader 3 only	75.0% (6/8)	55.6% (5/9)	64.7% (11/17)	100.0% (8/8)	55.6% (5/9)	76.5% (13/1 7)

Values are percentage (number)

that their suspicion for MAP decreased in 0, 2, and 2 cases, respectively (14.8% on average), while their suspicion increased (incorrectly) in 5, 4, and 3 cases, respectively (44.4% on average).

Associations between imaging findings and final pathology

Table 3 summarizes an exploratory analysis of each imaging finding and diagnosis category with the final diagnosis of MAP on pathology. There were statistically significant trends towards dark and thick intraplacental bands on T2W images and loss of retroplacental T2 dark zone being more common in those with MAP than without based on T2W only or T2W + DWI reads. Uterine bulging also tended to be more common in those with MAP based on the T2W only read (87.5% vs. 63.0%, $p = 0.036$) and T2W + DWI read (62.5% vs. 29.6%, $p = 0.069$). A finding of abnormal interface between placenta and myometrium was not significantly associated with MAP present based on the T2W only read (62.5% vs. 37.0%, $p = 0.14$); however, abnormal interface was significantly associated with MAP present based on the T2W + DWI read (100.0% vs. 63.0%, $p = 0.008$). The specific abnormalities of focal interruptions in the myometrial wall ($p = 0.016$), focal thinning ($p = 0.037$), and frank invasion ($p = 0.050$) each had marginally significant associations with MAP present on pathology.

Table 3. Associations between imaging findings and diagnosis with MAP on pathology

Findings from T2W images	T2W only reads[a]			T2W + DWI reads[a]		
	Pathologic group			Pathologic group		
	Invasion ($n = 24$)	No invasion ($n = 27$)	p value†	Invasion ($n = 24$)	No invasion ($n = 27$)	p value†
Heterogeneous signal within placenta	17 (70.8)	11 (40.7)	0.15	20 (83.3)	15 (55.6)	0.11
Increase/disorganized vascularity	13 (54.2)	10 (37.0)	0.41	13 (54.2)	10 (37.0)	0.42
Dark and thick intraplacental bands on T2WT2W	17 (70.8)	10 (37.0)	0.12	21 (87.5)	11 (40.7)	0.026
Loss of retroplacental T2 dark zone	19 (79.2)	9 (33.3)	0.021	22 (91.7)	16 (59.3)	0.064
Findings from T2W and/or DWI images						
Placenta previa	15 (62.5)	9 (33.3)	0.27	16 (66.7)	9 (33.3)	0.23
Uterine bulging	15 (62.5)	7 (25.9)	0.036	15 (62.5)	8 (29.6)	0.069
Tenting of bladder	4 (16.7)	2 (7.4)	0.45	5 (20.8)	2 (7.4)	0.44
Abnormal interface between placenta and myometrium	21 (87.5)	17 (63.0)	0.14	24 (100.0)	17 (63.0)	0.008
Irregular margins	15 (62.5)	12 (44.4)	0.33	18 (75.0)	13 (48.1)	0.18
Focal interruptions in the myometrial wall	15 (62.5)	10 (37.0)	0.13	20 (83.3)	10 (37.0)	0.016
Focal thinning	20 (83.3)	15 (55.6)	0.12	21 (87.5)	13 (48.1)	0.037
Frank invasion	4 (16.7)	0 (0.0)	0.082	5 (20.8)	1 (3.7)	0.050
Diagnosis						
Morbidly adherent placenta	17 (70.8)	12 (44.4)	0.16	23 (95.8)	15 (55.6)	0.020
Accreta	1 (4.2)	7 (25.9)	0.043	2 (8.3)	4 (14.8)	0.69
Increta	9 (37.5)	2 (7.4)	0.066	10 (41.7)	9 (33.3)	0.58
Accreta/increta	10 (41.7)	9 (33.3)	0.63	12 (50.0)	13 (48.1)	>0.99
Percreta	7 (29.2)	3 (11.1)	0.27	11 (45.8)	2 (7.4)	0.007
Percreta/increta	16 (66.7)	5 (18.5)	0.008	21 (87.5)	11 (40.7)	0.011

[a]Values are no. (%); reads from all three readers were included in the analysis

†Comparison of findings between pathologic groups using permutation test to account for multiple reads per case. No p value adjustment for the number of comparison

Inter-reader agreement

Table 4 summarizes inter-reader agreement for imaging findings and diagnoses for all readers together and for readers 1 and 3 who had prior clinical experience with reading placental DWI. For T2W-specific findings, agreement as assessed by kappa coefficients ranged from fair to good, depending on the reading session and whether three or two readers were analyzed. For the findings based on T2W + DWI images, agreement between readers 1 and 3 was excellent for placenta previa (κ = 0.88); good for focal interruptions in the myometrial wall (κ = 0.65); moderate for uterine bulging (κ = 0.43), tenting of bladder (κ = 0.45), abnormal interface between placenta and myometrium (κ = 0.46), and focal thinning (κ = 0.43); and poor for irregular margins (κ = 0.16), and frank invasion (κ = 0.00). Agreement tended to be lower between all three readers than between readers 1 and 3 only. There were no significant differences in agreement between the T2W only and T2W + DWI reads.

Discussion

In this pilot study, we did not find a significant difference in the diagnostic accuracy for detection of MAP when a DWI sequence was added to traditional T2W imaging. The sensitivity for the detection of MAP trended towards improvement with T2W + DWI compared of T2W images only, though accompanied by a trend towards slight decrease in specificity, neither of which were statistically significant.

Ultrasound is the primary imaging modality for the evaluation of MAP. Placental MRI is mainly used as an adjunct tool in the setting of equivocal ultrasound findings or in cases of unfavorable placental location like posterior placenta, where the visibility of the placental–myometrial interface on ultrasound is limited. Studies have shown no significant difference between ultrasound and MRI in their efficiency to diagnose invasive placentation, but given the lower cost and wide availability, ultrasound is still the imaging modality of choice for the suspected placenta accreta spectrum abnormalities [13]. There are multiple established MR imaging criteria for the diagnosis of MAP, including presence of placenta previa, heterogeneous signal intensity within the placenta, increased and disorganized vascularity, dark and thick intraplacental bands on T2WI, loss of retroplacental T2 dark zone, bulging of uterine contour, urinary bladder tenting, and abnormal interface between placenta and myometrium (including irregular margins of placenta, focal interruptions in myometrial wall, focal thinning, frank invasion of pelvic organs; Figs. 2, 3). Of the listed features, presence of dark and thick intraplacental bands on T2WI is pathologically proven to be most commonly associated with invasive placentation in multiple prior studies [14, 15]. In comparison, our study demonstrated abnormal interface between placenta and myometrium to be the most common MRI finding associated with MAP present (87.5% with T2WI and 100% with T2W + DWI), followed by loss of retroplacental T2 dark zone and dark intraplacental bands on T2WI. The overall sensitivity and specificity for the diagnosis of invasive placentation was found to be 70.8%

Table 4. Inter-reader agreement

Findings from T2W images	T2W only reads				T2W + DWI reads			
	Overall agreement (all readers)		Overall agreement (readers 1 and 3)		Overall agreement (all readers)		Overall agreement (readers 1 and 3)	
	κ	(95% CI)	κ	(95% CI)	κ	(95% CI)	κ	(95% CI)
Heterogeneous signal within placenta	0.37	(0.06, 0.67)	0.30	(− 0.16, 0.72)	0.28	(0.01, 0.57)	0.76	(0.36, 1.00)
Increase/disorganized vascularity	0.30	(− 0.06, 0.61)	0.52	(0.09, 0.88)	0.30	(− 0.02, 0.61)	0.33	(− 0.12, 0.76)
Dark and thick intraplacental bands on T2W	0.46	(0.16, 0.75)	0.53	(0.16, 0.88)	0.51	(0.23, 0.78)	0.65	(0.32, 1.00)
Loss of retroplacental T2 dark zone	0.37	(0.04, 0.68)	0.53	(0.11, 0.88)	0.39	(− 0.06, 0.74)	0.44	(− 0.03, 0.87)
Findings from T2W and/or DWI images								
Placenta previa	0.84	(0.60, 1.00)	0.76	(0.41, 1.00)	0.92	(0.76, 1.00)	0.88	(0.64, 1.00)
Uterine bulging	0.14	(− 0.13, 0.40)	0.16	(− 0.27, 0.56)	0.23	(− 0.07, 0.52)	0.43	(− 0.01, 0.77)
Tenting of bladder	0.07	(− 0.07, 0.28)	− 0.09	(− 0.19, 0.00)	0.36	(− 0.08, 0.77)	0.45	(0.00, 1.00)
Abnormal interface between placenta and myometrium	0.29	(0.20, 0.33)	0.88	(0.61, 1.00)	0.39	(− 0.01, 0.76)	0.46	(− 0.13, 1.00)
Irregular margins	0.24	(0.01, 0.43)	0.20	(− 0.19, 0.55)	0.38	(0.15, 0.62)	0.16	(0.02, 0.45)
Focal interruptions in the myometrial wall	0.13	(− 0.11, 0.35)	0.20	(− 0.21, 0.64)	0.36	(0.05, 0.66)	0.65	(0.30, 1.00)
Focal thinning	0.32	(0.12, 0.56)	0.65	(0.32, 1.00)	0.33	(− 0.00, 0.62)	0.43	(0.11, 0.76)
Frank invasion	0.16	(− 0.03, 0.33)	− .06	(− 0.16, 0.00)	− 0.06	(− 0.12, 0.00)	0.00	–
Diagnosis								
Morbidly adherent placenta	0.20	(− 0.11, 0.47)	0.64	(0.20, 1.00)	0.48	(0.10, 0.81)	0.85	(0.47, 1.00)
Accreta/increta	0.08	(− 0.14, 0.36)	0.49	(0.04, 0.88)	0.04	(− 0.18, 0.28)	0.16	(− 0.31, 0.60)
Percreta	0.27	(0.09, 0.38)	0.11	(− 0.28, 0.67)	0.16	(0.03, 0.27)	0.27	(− 0.15, 0.68)
Percreta/increta	0.36	(0.02, 0.64)	0.52	(0.09, 0.88)	0.34	(0.02, 0.68)	0.74	(0.35, 1.00)

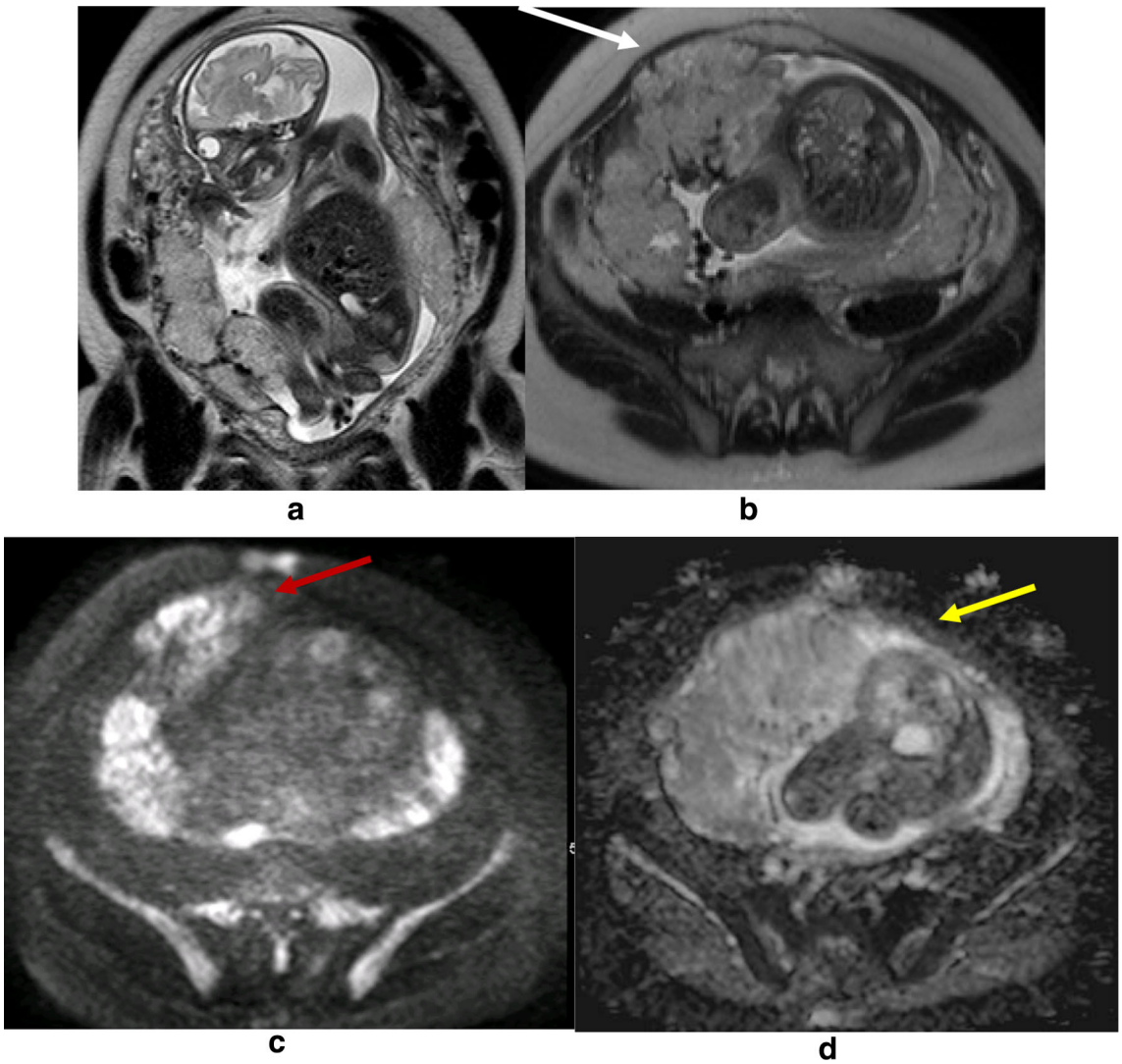

Fig. 2. 33-week-old gestation with ultrasound suspicious for placenta percreta. T2W images (a = coronal and b = axial) shows area of increased vascularity and area of focal bulging into the anterior abdominal wall (white arrow in **B**). DWI b = 800 image was limited due to the resolution, however showed an area of increased signal in the anterior myometrium (red arrow in **B**). ADC map shows the bright myometrium seen lateral to this (yellow arrow in **D**) area but not in this region of invasion. This was confirmed as placenta percreta on surgery and pathology.

and 55.6% with T2WI only and 95.8% and 44% with T2WI + DWI, which is comparable to prior studies [16].

There are some inherent advantages of DWI sequences in the evaluation of placental tissue that prompted our current evaluation. Primarily, due to high cellularity and ample cytoplasm within the placenta, Brownian principles of molecular water motion result in placental signal that is comparatively hyperintense to myometrium on DWI sequences (Fig. 4). Morita and colleagues showed that inherent differences in the signal intensities between the placenta and myometrium on DWI images at higher B values were more useful in delineating an abnormal placenta–myometrium interface than conventional MRI sequences [11]. They further describe that with conventional MRI sequence (i.e., T2W-TSE), placenta and myometrium showed similarly moderate high signal intensity, making it difficult to delineate placenta from myometrium and has an additional advantage of being relatively resistant to motion.

In our institution, T2WI are acquired in 3-mm slice thickness utilizing Ultrafast Spin-Echo sequence (SSH-TSE), which by its faster acquisition time greatly reduces motion artifacts. This improves image definition and contrast. Like our practice, most other institutions also use faster image acquisition techniques like Ultrafast spin-echo (SE), Balanced gradient-echo (GE), Spoiled gradient-echo (GE) sequences for placental imaging. Yamashita et al. reported that the distinction between the placenta and uterus was better with HASTE (Ul-

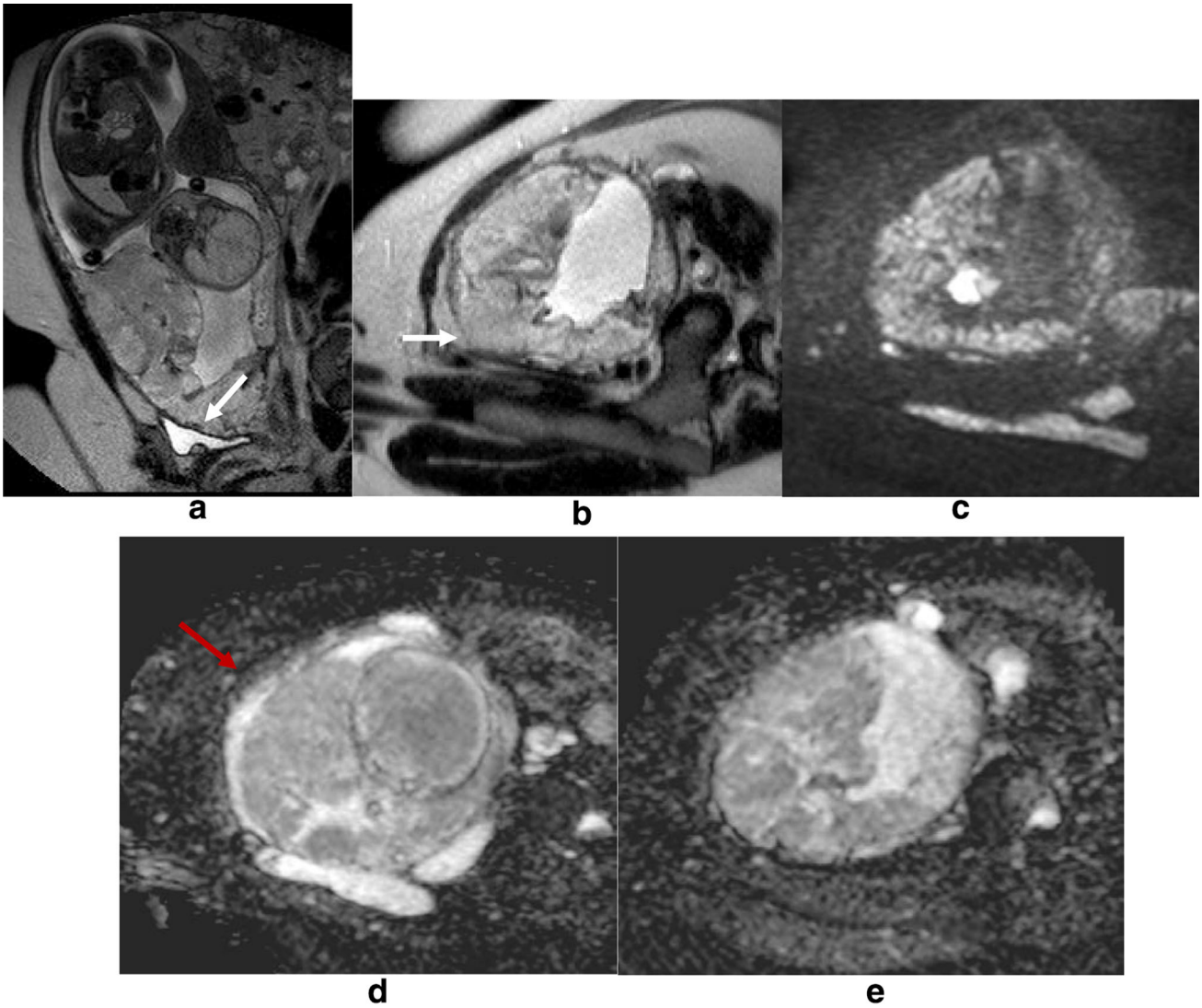

Fig. 3. 34-week-old gestation with placenta previa, previous history of two C-sections. T2W images (a = sagittal and b = axial) show thinning of the myometrium in the lower uterine segment with areas of absent myometrium (arrow in **A**, **B**). DWI b = 800 **C** image shows poor resolution and hence difficult to evaluate the myometrial wall. ADC map **D** at a higher level shows the higher signal intensity in the myometrium (red arrow in **D**) compared to the placenta which makes differentiation relatively easy. ADC map in the lower uterine segment **E** shows absence of the same bright myometrium suggesting absence or thinning. This was diagnosed as placenta increta on pathology.

trafast SE) imaging than with turbo spin-echo (TSE) T2-weighted imaging or FLASH (Spoiled GE) imaging [17]. Kim and colleagues showed the utility of True FISP (Balanced GE) and HASTE (Ultrafast SE) sequences in the diagnosis of placenta accreta [18]. So, with the availability of these faster imaging acquisition techniques there is improved image quality, that may help to explain why our readers did not report any increased advantageousness of additional DWI sequence to conventional T2W in the diagnosis of MAP. Additionally, based on our results, if DWI is not significantly increasing the accuracy or reader confidence for diagnosis of MAP, one can exclude routine inclusion of DWI sequence in prenatal MRI and prevent this additional source of absorbed radiofrequency energy in both mother and fetus.

Reader agreement was poor for majority of the features without or with the addition of DWI. Among all the readers' highest inter-reader agreement was for the presence of placenta previa ($\kappa = 0.92$). Our study shows that even among reader whose practice includes prenatal MRI, experience and familiarity with the features MRI features of MAP is limited. The results from our study are comparable to prior studies which report poor–moderate interobserver agreement on MRI findings [19]. This suggests a need for reader training and qualification on standardized image sets for implementation of MRI for diagnosis of MAP. Like prenatal MRI, ultrasound is

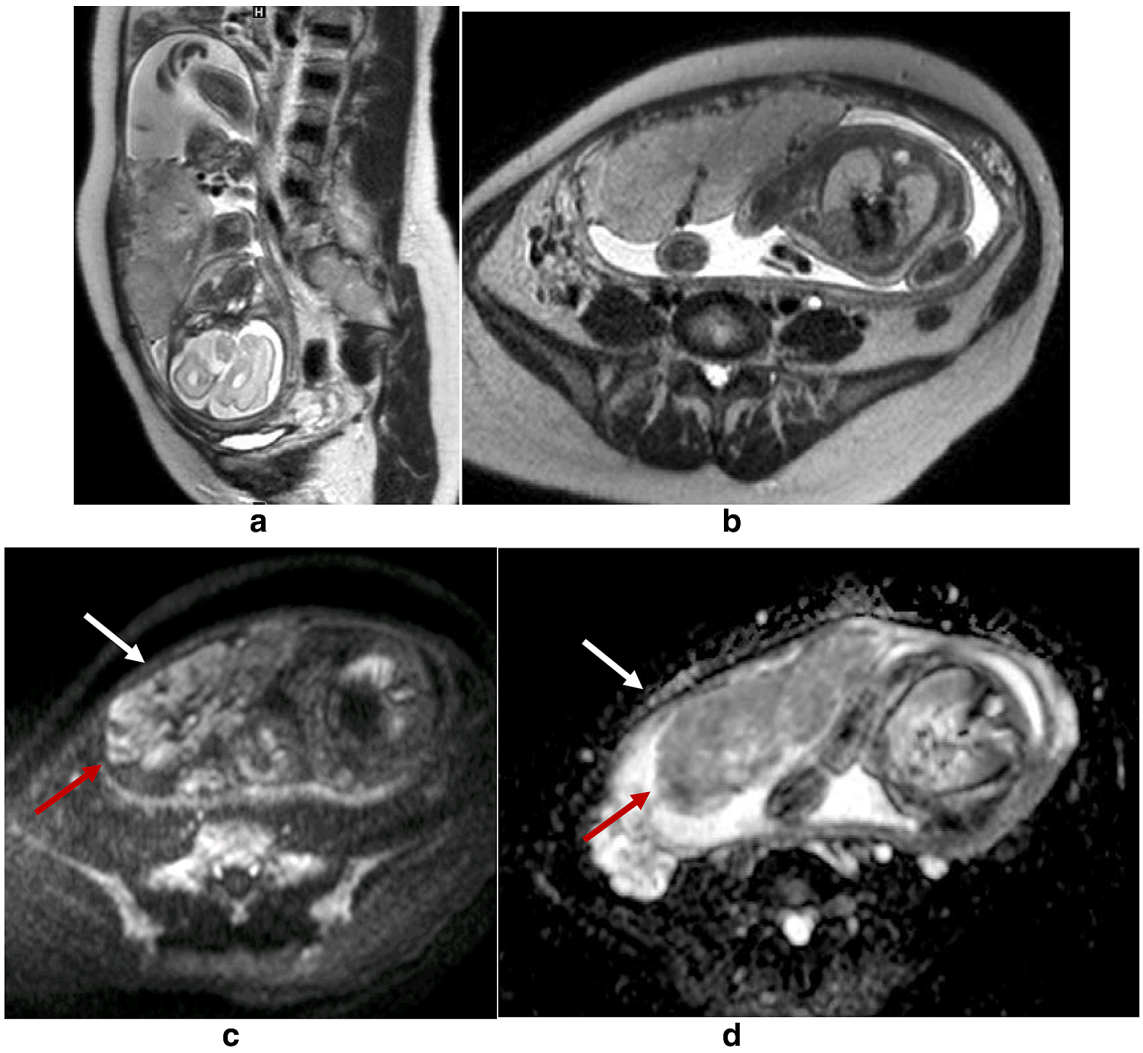

Fig. 4. 28-week-old gestation, history of previous one C-section, and suspicion for placenta accreta on US. T2W images show an anterior placenta with no imaging signs suspicious for placental invasion. Note the difference in signal intensity on the DWI image and ADC map between the placenta (red arrow) and the uterine wall (white arrow).

also reported to have only moderate overall interobserver agreement for the prediction of placental invasion with significant interobserver variability [20].

We found with T2W + DWI that the association between imaging diagnosis of accreta and invasion on pathology became a little weaker and the association between imaging diagnosis of percreta and invasion on pathology became a little stronger, though some of these fluctuations could be due to relatively small sample size. We did not find significant difference in MRI findings between invasion sub-types; again this could be due to sample size of each group was relatively small. Increased number of findings from the T2W + DWI review tended to correlate with the pathology diagnosis than from the T2W alone review.

In this study, each case was evaluated in a random order by individual readers who were blinded to the clinical data and with a waiting period between image sets to avoid recall bias, and the availability of histopathology in all cases as the standard of reference. The most prominent limitation of our study is the small number of cases (n = 17) available with pathologic assessment of the placenta. In body MR, DWI is a relatively new application with limited resolution of images compared to T2W imaging. Specifically, there is lack of experience in DWI imaging of the placenta as most institutions do not perform DWI in placental evaluation as a routine. There is a lack of standardized terminology and diagnosis of MAP across various disciplines including Radiology, Obstetrics, and Pathology; for example, placenta increta by definition is when the placenta penetrates the myometrium and percreta when placenta reaches up to or through the serosa; however, on imaging uterine serosa is not seen as separate structure, so a placenta percreta on imaging can still be a increta by pathology.

Conclusion

With the current imaging technique, addition of DWI sequence to the traditional T2W images cannot be shown to significantly increase the accuracy or reader confidence for diagnosis of MAP. Addition of DWI improves identification of abnormalities in the placental–myometrial interface. Thus, future studies with larger cohorts with trained readers are needed to decide whether DWI improves MRI diagnosis of placenta accreta spectrum abnormality.

Compliance with ethical standards

Disclosure of potential conflicts of interest None.

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Ethical approval All procedures performed in studies involving human participants 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.

Informed consent Retrospective study, hence no informed consents were obtained.

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