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ORIGINAL ARTICLE

Chemical Shift Artifact on Steady-State MRI Sequences for Detection of Vesical Wall Invasion in Placenta Percreta

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Abstract

Background Antenatal diagnosis of the invasiveness of a placenta percreta helps in planning the surgical approach, reducing blood loss and morbidity. Doppler sonography is the mainstay diagnostic modality with a sensitivity of 80–95 %. With the advent of high magnetic field MRI techniques, there has been recent interest in evaluation of placenta by MRI. On an extensive PUBMED search, we could not find any citations describing imaging, ultrasound, or MRI features to evaluate vesical wall invasion by placenta percreta.

Purpose We attempt to evaluate transmyometrial vesical wall invasion by placenta percreta using chemical shift artifact as a marker of intact bladder-myometrial interface on steady-state MRI sequences.

Materials and Methods This is a prospective observational study, conducted at a university hospital. We have compiled clinico-radiological criteria for diagnosis of invasive placentae based on the existing body of evidences, in four patients. We further go on to analyze a specific proposed sign on a newly introduced MR imaging sequence i.e., loss of chemical shift artifact (India ink line) on steady-state GRE sequence (TrueFISP), to diagnose transmyometrial vesical invasion in placenta percreta.

Results Though the sample size is small, the sensitivity, specificity, positive, and negative predictive value of the proposed sign for the purpose was 100 %.

Conclusions(s) Loss of chemical shift artifact (India ink line) on steady-state GRE sequences at the vesico-

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myometrial junction in case of invasive placentae confirms vesical wall invasion, a prospective diagnoses of which can help in planning the surgical protocol and preventing potentially fatal blood loss.

Keywords Placenta percreta · Placental MRI · Steady-state sequences · Chemical shift artifact

Introduction

Spins (protons) from both fat and water lie at the genesis of MR signal generation. Carbon atoms in fat, however, provide greater electron cloud surrounding the protons, thereby shielding them from effects of external magnetic field. As a result, fat spins precess at a lower frequency than water. The shift in Larmor frequency between water protons and fat protons during concomitant precession is referred as chemical shift [1]. At 1.5 T, protons from fat resonate at a point approximately 220 Hz less than the water protons resonance frequency which leads to a pixel shift in frequency encoding direction. This pixel shift of fat relative to water is known as chemical shift artifact. In spin echo (SE) sequences, the mis-mapping will occur in the frequency encoding direction, and show up as a bright band on one side and a dark band on the other side of a fat-soft tissue interface. In gradient refocused echo (GRE) sequences, the mis-mapping occurs in all directions, and is known as the "india ink artifact" [2]. Due to the absence of refocusing of field in-homogeneities, long TE GRE sequences are actually T2*-weighted rather than true T2-weighted sequences like that in the SE family. The effects of chemical shift are hence, more prominent in GRE sequences, such as fast multi-planer spoiled gradient echo (FSPGR) and True FISP (fast imaging with steady-state precession), as a result in cycling of fat and water protons in and out of phase over time [2, 3]. This persistent India ink artifact at the interface of abdominal fat with visceral structures results in a better visualization of the visceral outline [3].

Recently, chemical shift artifact has been evaluated as a diagnostic tool in diagnosis of renal angiomyolipoma, adrenal adenoma, hepatocellular carcinoma with fat degeneration, and to rule out capsular invasion by renal tumors [4, 5]. In last several years, there has been increase in interest over use of MRI in characterization of invasive placentae. However, to date, no MRI surrogate has been established for detection of bladder wall invasion in cases of placenta percreta, which, if missed, can inflict serious surgical complications. The purpose of this study is to evaluate the role of chemical shift artifact present inherently in steady-state MR sequences to predict vesical wall invasion in cases of placenta percreta.

Patients and Methods

Patients

Between October 2011 and November 2012, 20 patients in the second and third trimester of pregnancy presenting with acute vaginal bleeding, a diagnosis of placenta previa, and at least one previous cesarean section were referred to us for color doppler examination. Based on the features on this investigation, seven cases were diagnosed as having invasive placenta disorders. On requisition of the referring clinician and having obtained informed consent from the patient, MRI was performed to further evaluate the depth of placental invasion, in 12 patients. Complete clinical and pathological data were eventually available in four cases for analysis.

Methods

Gray-scale B-mode sonography using a 3.5 MHz curved electronic array transducer (IU-22, Philips medical systems, The Netherlands and Xario, Toshiba corp inc., Japan) was performed initially to assess the placental tissue homogeneity and echogenicity patterns and to look for placental lacunae. Assessment of the placenta was completed using superimposed color Doppler flow with criteria described by Chou et al. [6]. All US Doppler (and MR exams) were obtained with a partially full bladder. MRI was performed on a 1.5 T superconducting system (Magnetom Avanto, Seimens Medical System, Erlangen, Germany) equipped with an actively shielded whole-body magnetic field gradient set using a large size receive and transmit radio frequency body coil. Following a localizer scan, sagittal, axial, and coronal half-Fourier acquisition with single-shot turbo spin echo (HASTE) (TR/TE/NEX/Φ of 1200/90/1/17°; slice thickness 6 mm with D.F 20 % and phase oversampling of 30 %; resolution 256 × 80; Bandwidth 425 Hz/Pz) were acquired. Next, multi-planner imaging was done using GRE sequence with steady-state precession (True FISP) (TR/TE/NEX/Φ of 3.69/1.85/1/60°; slice thickness 6 mm with D.F 20 % and phase oversampling of 20 %; resolution 256 × 90; Bandwidth 501 Hz/Pz).

All studies were done during free breathing without any sedation to the mother. The entire examination time was 20–25 min. Careful explanation of the procedure and pre-/intra-procedure oral glucose administration to reduce maternal anxiety and fetal movement, respectively, thereby helped us in availing maximum patient co-operation. Furthermore, patients were monitored using close circuit television system to ensure constant contact between the patient and the control room during the procedure. The investigations were performed with due informed consent

from the patients/legal guardians, and as per established evidence-based or literature-supported guidelines. No separate I.R.B approval is usually needed for such investigations in our institution.

Results (Tables 1, 2)

Four cases of placental adhesive disorders were included in the study of which one was undiagnosed by US and color Doppler study. MRI findings were confirmed by surgery and pathological examination in all four cases, and confirmed to the pre-operative diagnosis made by MRI in all. One of these four cases (Patient 1) revealed loss of India ink line at bladder-myometrial interface suggesting bladder wall invasion (Fig. 1). In patient 3 of this study (Fig. 3), US showed central placenta previa, no evidence of enhanced subplacental vascularity or hypervascularity at bladder-myometrial interface was noted. One small irregular intraplacental anechoic area was observed raising suspicion of placental lacuna, however, power Doppler failed to reveal flow in the lesion. Still, in view of strong clinical suspicion and persistent vaginal bleed, MRI was performed to rule out placenta accreta. MRI showed few dark intraplacental bands and areas of abnormal uterine bulging. Bladder-myometrial interface was maintained except for a focal loss of outline by India ink line artifact. The area was reassessed using Doppler which revealed hypervascularity with pulsatile arterial flow. MRI diagnosis of placenta percreta with focal bladder invasion was given. Modified hysterectomy operations were performed in both these cases in which the bladder was partially mobilized beneath the percreta invasion site via the paravesical spaces. Both these cases resulted in blood loss of more than 2 l. In remaining 2 cases (Figs. 2, 3 and 4), India ink line artifact was maintained at the interface suggesting non-invasive nature of the disease. Total hysterectomy was performed after these two cases with lesser blood loss during surgery. All the patients survived and were discharged in stable condition.

Although we agree that the number in our study is not sufficient, intermediary results based on these 4 cases suggest that the loss of chemical shift artifact (India ink line) on GRE-based steady-state sequence (True FISP) has a sensitivity, specificity, positive, and negative predictive value of 100 %, for prediction of vesicle wall invasion in cases of placenta percreta.

Discussion

Placenta accreta is a potentially life threatening condition which includes various abnormalities of placental implantation in which placenta invades the myometrium. Placenta accreta involves myometrial invasion, placenta increta involves deep myometrial invasion, and placenta percreta invades through the serosal layer of the uterus with potential invasion of adjacent bladder or bowel loops [8]. Accurate identification of extent of invasion helps the surgeons to plan the nature of hysterectomy and doing so, decrease blood loss and morbidity. In cases of bladder wall invasion, the hysterectomy is modified using wide margins of surgical excision to avoid traversing the highly vascular placenta [6, 7]. Ultrasound and color Doppler imaging is at present the mainstay of diagnosis of placenta accreta. According to a study conducted by Chou et al. in 17 patients of placenta accreta, sensitivity of US with color Doppler in diagnosis of placenta accreta was 82.4 % and the specificity was 96.8 % [6].

Off late, there have been many studies evaluating role of MRI in diagnosis of placenta accrete [6–10]. All above

Table 1 Summary of patient history and imaging features

Patient	Age (years)	Gestational age (weeks)	Prior cesarean section	USG and Doppler findings	MRI findings	True FISP sequence
I	30	25	1	Intraplacental lacunae, enhanced but interrupted subplacental vascularity	Dark heterogeneous bands, focal uterine bulging	Loss of India ink line at bladder-myometrial interface.
II	37	26	2	Intraplacental lacunae, enhanced subplacental vascularity	Heterogeneous signal intensity in placenta, abnormal uterine bulging and multiple dark heterogeneous bands	Bladder-myometrial interface completely outlined by India ink line artifact
III	27	31	1	Normal subplacental vascularity and bladder interface	Few dark intraplacental bands and areas of abnormal uterine bulging	Focal loss of outline by India ink line artifact
IV	35	27	2	Intraplacental lacunae, enhanced but interrupted subplacental vascularity	Heterogeneous signal intensity in placenta, intraplacental hemorrhage and multiple dark heterogeneous bands	Bladder-myometrial interface completely outlined by India ink line artifact

Table 2 Summary of imaging diagnosis, operative procedure, and pathological correlation

Patient	US diagnosis	MRI diagnosis	Delivery method	Estimated blood loss (ML)	Pathological diagnosis
I	Placenta previa with placenta accreta	Placenta percreta with bladder invasion	Modified Cesarean hysterectomy	3,500	Percreta
II	Placenta previa with placenta accreta	Placenta accreta without bladder invasion	Cesarean hysterectomy	800	Accreta
III	Placenta previa	Placenta percreta with bladder invasion	Modified Cesarean hysterectomy	2,500	Percreta
IV	Placenta previa with placenta accreta	Placenta accreta without bladder invasion	Cesarean hysterectomy	2,000	Accreta

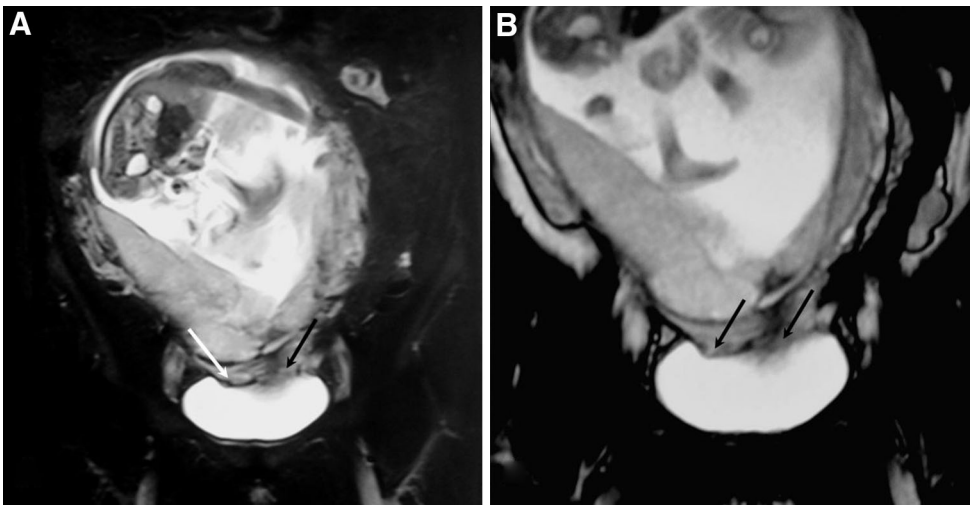

Fig. 1 Patient 1. MRI for assessment of extent of placental invasion revealed dark heterogenous bands near cervix with focal uterine bulging. **a** Coronal and **b** oblique coronal MR shows loss of india ink line at bladder-myometrial interface (*black arrow*) suggesting a diagnosis of Placenta percreta with bladder wall invasion. Note the non-invaded regions (*white arrow*) showing persistence of India ink line. *Color Doppler* in this patient concluded a central placenta previa with placenta accrete

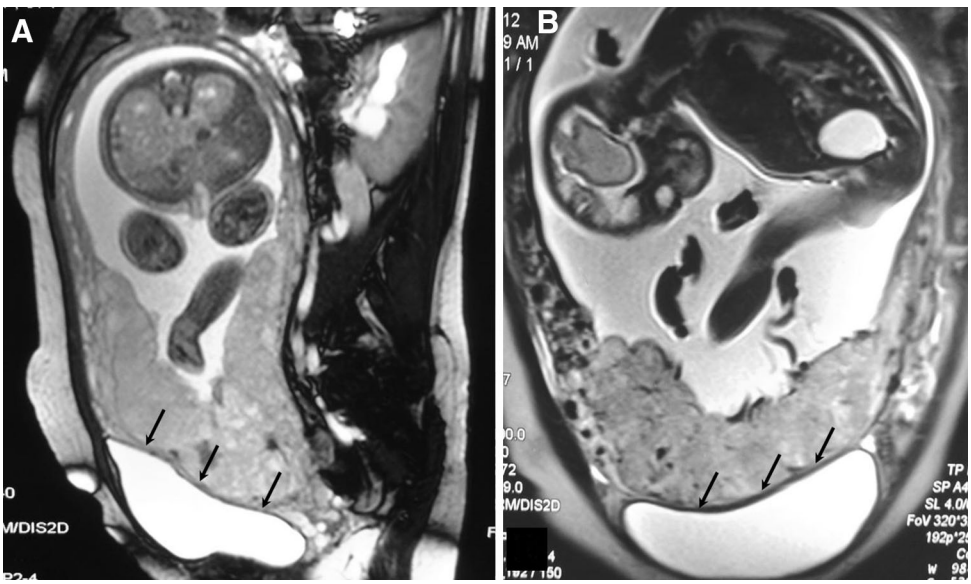

Fig. 2 Patient 2. **a** Sagittal and **b** Coronal MRI shows maintained bladder-myometrial interface with a completely maintained India ink line (*arrows*), in spite of a heterogenous placental intensity, abnormal uterine bulging and multiple dark heterogenous bands. MRI diagnosis of placenta accreta without bladder invasion was given. *Color Doppler* revealed central placenta previa with placenta accreta

studies found the role of MRI as a correlative and/or problem solving tool in difficult cases. In tandem to the above workers, we also feel that MRI may not be given first preference for making an initial diagnosis of invasive placentae, which can be effectively made by a much cost-effective modality i.e., Ultrasonography. However, as far

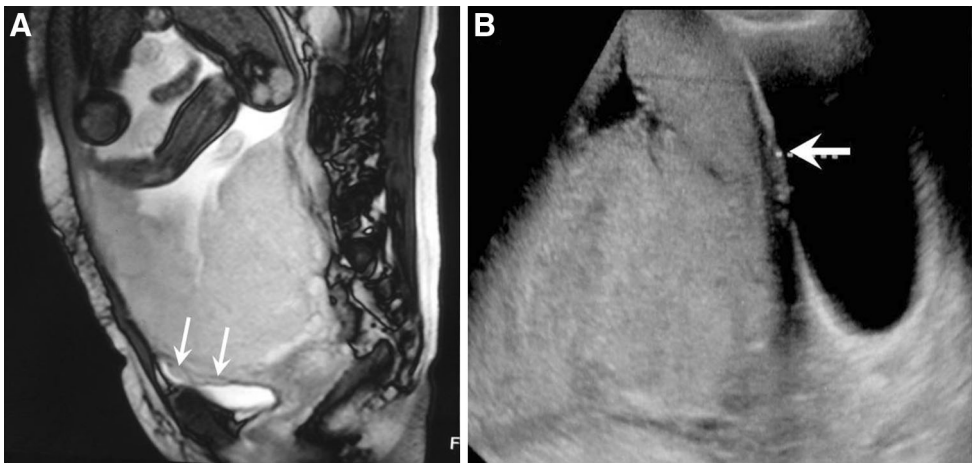

Fig. 3 Patient 3. **a** MRI revealed focal loss of India ink line artifact raising a suspicion of placenta percreta with focal bladder invasion, not suspected on initial sonography. **b** Focused Doppler sonography in this case, when performed retrospectively after MRI raised suspicion of vesical wall invasion, shows central placenta previa with enhanced subplacental pulsatile arterial vascularity. This sign has been mentioned to diagnose placenta accrete with vesical wall invasion with high specificity

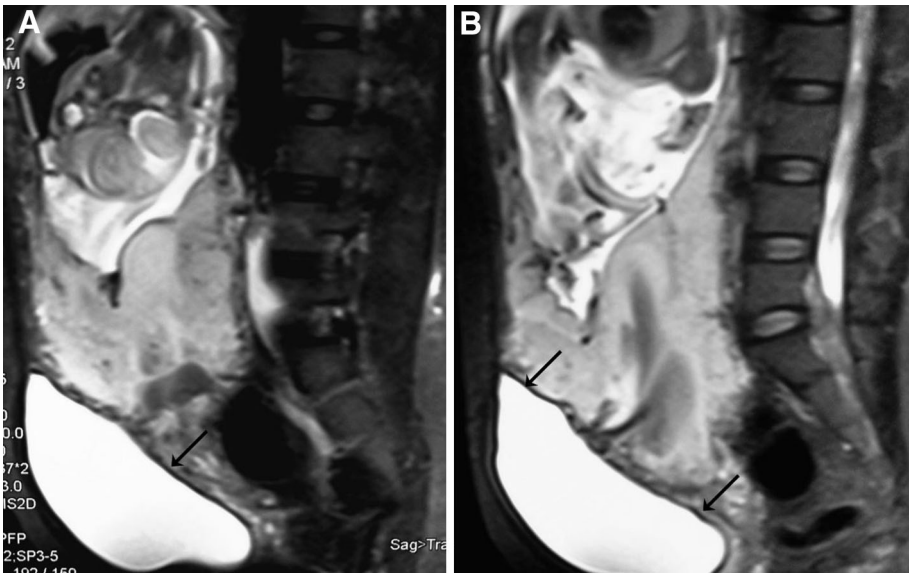

Fig. 4 Patient 4. Sagittal MRI shows a maintained bladder-myometrial interface and a complete India ink line artifact; associated heterogenous signal intensity in placenta, intraplacental hemorrhage, and multiple dark heterogenous bands are also seen. MRI diagnosis of placenta accreta was made ruling out bladder invasion. *Color Doppler* revealed central placenta previa with placenta accrete

as evaluation and confident comment on transmyometrial invasion of vesical wall is concerned, MRI is superior to ultrasonography. Out of four patients, ultrasound missed vesical wall invasion in 1 case, while in the other case bladder invasion was suspect by Doppler on retrospect after MRI. Dwyer et al. (2006) studied 32 patients who had both sonography and MRI prenatally to evaluate for placenta accreta. There was no statistical difference in sensitivity or specificity between sonography and MRI according to this study [9]. However, this study was not without bias as high-risk patients with strongly suggestive negative or positive sonographic findings were systematically not referred for MRI in their study.

Depending on the MR imaging parameters, steady-state sequences can be broadly grouped into 3 classes, the details of which are out of scope of this article and interested readers are referred to specialized texts [11]. The sequence used in the present study, True FISP (Seimens Medical System, Erlangen, Germany), basically belongs to the group of fully refocused (balanced) steady-state sequences, where both the positive and negative components of the decaying MR signal (known as free induction decay) are sampled [11]. The chemical shift artifact is clinically most often recognized in fluid-filled organs with surrounding fat such as bladder and orbit. The phenomenon is already being utilized in recognizing fat-containing tumors in brain with CSF interface, in detection of adrenal adenomas, renal angiomyolipomas, and to detect lipomatous metaplasia in patients having myocardial infarction [3, 4, 12, 13]. Israel et al. studied 23 patients of renal angiomyolipoma and

were able to demonstrate india ink artifact within the mass or at its interface with the kidney in all of the patients [5]. Recently, its role in prediction of renal capsule invasion by renal cell carcinomas and in assessment of resectability in mediastinal tumors also has been advocated [11, 12]. In a study of assessment of resectability in mediastinal tumors by Monti et al., complete resection was always successfully carried out in 14 patients based on the integrity of India ink artifact, while in one case MR correctly anticipated non-resectability [12]. We extend this concept of loss of fat plane by tumors leading to loss of chemical shift artifact to placental invasion. After all, one must keep in mind that there can be multiple pathological causes of tissue invasion.

We recognize that there is a significant weakness in this study to be attended. The sample size was limited to four patients which is low for this study to hold statistical significance. However, given the rarity of abnormal placentation, a large sample group is difficult to gather in future, which would be optimal to evaluate a larger number of patients for similar studies. Another pitfall in this study was to assess only one MRI feature i.e., loss of chemical shift artifact to assess the invasion and not correlating with other features such as degree of placental heterogeneity, number of intraplacental bands, etc. Follow-up retrospective multicenter studies on MRI of placenta accrete/percreta may further support our findings. Furthermore, all the cases included in this study have been assessed using slice thickness of 6 mm, resolution of 256 $\times$ 90, and bandwidth 501 Hz/Pz. We have tried using increase FOV, narrower bandwidth, and reduced data acquisition matrix of 63 $\times$ 128 with variable results (in patients not included in this study). A large multicenter study is needed to hold any statistical validity in deciding the lower limit of resolution.

MRI is an expensive investigation and its use in routine examination of placenta is not justified just by detecting the presence or absence of invasive placenta, which can well be made using Color Doppler ultrasound by an experienced sonologist. However, detection of vesical wall invasion by demonstration of loss of chemical shift artifact (India ink line) at vesico-myometrial interface in cases of placenta percreta helps to plan the surgery and to avoid the potentially devastating outcome during surgery.

Acknowledgments None.

Compliance with ethical requirements and Conflict of interest These studies were performed as per routine clinical referral following standardized technique for gestational MRI. Informed consent from patients were taken and has been already mentioned. No novel intervention mandating ethical clearance over and above the informed consent and clinical referral was hence required. The authors report no conflict of interest.

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