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SCIENTIFIC ARTICLE

MR imaging of skeletal soft tissue infection: utility of diffusion-weighted imaging in detecting abscess formation

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Abstract
Purpose Our objectives were to assess if diffusion-weighted imaging (DWI) can help identify abscess formation in the setting of soft tissue infection and to assess whether abscess formation can be diagnosed confidently with a combination of DWI and other unenhanced sequences.
Methods Eight cases of soft tissue infection imaged with MRI including DWI were retrospectively reviewed.
Results Two male and six female patients were studied (age range 23–50 years). Unenhanced MRI including DWI was performed in all patients. Post-contrast images were obtained in seven patients. All patients had clinically or surgically confirmed abscesses. Abscesses demonstrated restricted diffusion. DWI in conjunction with other unenhanced imaging showed similar confidence levels as post-contrast images in diagnosing abscess formation in four cases. In two cases, although the combined use of DWI and other unenhanced imaging yielded the same confidence levels as post-contrast imaging, DWI was more definitive for demonstrating abscess formation. In one case, post-contrast images had a better confidence for suggesting abscess. In one case, DWI helped detected the abscess, where gadolinium could not be administered because of a contraindication.
Conclusion This preliminary study suggests that DWI is a useful adjunct in the diagnosis of skeletal soft tissue abscesses.

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Keywords Diffusion-weighted imaging (DWI) · MRI · Soft tissue abscess

Introduction

Musculoskeletal sepsis is a common cause for referral to emergency rooms with the majority suffering from cellulitis or soft tissue abscess [1]. Differentiation of infective processes of soft tissue from non-infective processes can be a critical factor in determining patient survival [2, 3]. Clinical presentation of soft tissue infection in the early stages can be vague, leading to diagnostic delays [3, 4]. MRI is the imaging modality of choice in the evaluation of soft tissue infection [5, 6]. However, conventional MR sequences may be non-specific during early stages of infection [7, 8]. Life-threatening conditions such as pyomyositis and necrotizing fasciitis can be difficult to distinguish from entities like muscle strain, hematoma, venous thrombosis, non-infectious myositis and myonecrosis [3, 9–11]. While cellulitis and infectious myositis are managed by antibiotic therapy, the presence of an abscess warrants drainage [4, 8, 12, 13]. Hence, detection of abscess formation is crucial in the setting of soft tissue infection.

DWI is increasingly employed in musculoskeletal imaging [14]. In neuroradiology, it has been shown to be effective at differentiating intra-cerebral abscess from other cystic neoplasms [15]. Although some authors [16] have been skeptical about the utility of DWI in the assessment of soft tissue infection, others [17, 18] have espoused its utility in different parts of the body including the spine and the head and neck. There is a paucity of literature assessing the role of DWI in evaluation of skeletal soft tissue abscesses.

The purpose of this study was to evaluate the utility of DWI in identifying abscess formation in the setting of suspected

Table 1 Summary of imaging features and clinicopathologic correlation in the eight patients

Case no.	Age/sex	Clinical presentation	WBC ($\times 10^6$)	DWI & unenhanced images	Imaging diagnosis	Post-gadolinium imaging	Final diagnosis
1	42F	IV drug abuser. 5-day h/o of pain and swelling of the calf. ?DVT ? necrotizing fasciitis	17,000	Extensive edema in calf muscles. Linear intramuscular and intermuscular foci of restricted diffusion seen	Pyomyositis	DWI restricting foci showed non-enhancement but mild rim enhancement	Surgical debridement performed and abscesses confirmed. *Staphylococcus aureus* cultured. Histology of debrided tissue confirmed findings of purulent infection
2	23F	10-day h/o worsening knee/thigh pain and swelling. Mild intermittent fever. ? septic arthritis of the knee	48,000	Extensive fascial edema and thickening. Small intermuscular fluid restricting on DWI	Infectious fasciitis with small intermuscular abscesses	DWI restricting foci showed mild/ equivocal rim enhancement	Surgical debridement performed and fasciitis and small abscesses confirmed. *Streptococcus pyogenes* cultured.
3	38 M	Diabetic with 3-week h/o thigh pain and swelling. Afebrile	15,900	Extensive vastus lateralis edema over 30 cm with 6 × 2 × 2 fluid collection within it showing avid restricted diffusion	Pyomyositis	Avid peripheral enhancement around the fluid collection that restricted diffusion	Surgical debridement and drainage performed and abscess confirmed. *Staphylococcus aureus* cultured.
4	28F	Discoid lupus on steroids. Ankle pain. ? Osteomyelitis? Cellulitis. No h/o fever	14,000	Tubular fluid collection in the subcutaneous tissue showing avid restricted diffusion and surrounding edema	Subcutaneous abscess and cellulitis	Avid peripheral enhancement around the fluid collection that restricted diffusion	Incision and drainage performed and abscess confirmed. *Streptococcus pyogenes* cultured.
5	33F	2-week h/o progressive medial thigh pain and mild/intermittent fever	13,600	Extensive adductor muscle edema with small foci of restricted diffusion. No encapsulated fluid collections on T2-W images	Pyomyositis	Extensive rim enhancement with restricted diffusion in areas of expansile rim enhancement	Many pus cells in ultrasound-guided turbid aspirate. Near-complete resolution with antibiotics on 3-month follow-up MRI.
6	24F	H/o SLE on steroids. 10-day h/o increasing low back pain and occasional fever	28,200	Large gluteal fluid collection arising from SI joint with avid restricted diffusion	Gluteal abscess arising from SI joint	Large rim enhancing abscess	Ultrasound-guided abscess drainage done followed by IV antibiotics. *Streptococcus pneumoniae* cultured.
7	49 M	2-month h/o left paraumbilical mass - ? Sarcoma ?abscess	12,300	10×5 cm intramuscular mass-like heterogeneous high signal in external oblique. Foci of avid restricted diffusion seen.	Chronic intramuscular abscess	Marked peripheral enhancement around the mass	Surgical excision – "Inflammatory Mass". Pathology showed findings consistent with chronic abscess cavity. *E. Coli* cultured
8	50F	Diabetic with mild fever and mild/vague right-sided pelvic pain. ? Septic arthritis right hip	8,200	11 × 12 × 6 cm focus of edema in the gluteal fat with small 2 × 4 cm deep fluid-filled focus showing restricted diffusion.	Infectious panniculitis with small abscess	Gadolinium not administered. On dialysis for renal failure.	Surgical debridement performed and pockets of pus confirmed. *Enterobacter cloaceae* cultured

Table 2 Summary of results for confidence in suggesting abscess formation

Case no.	Unenhanced MRI including DWI	Post-gadolinium sequences
1	Likely	Likely (DWI more suggestive)
2	Likely	Likely (DWI more suggestive)
3	Definite	Definite
4	Definite	Definite
5	Likely	Definite
6	Definite	Definite
7	Likely	Likely
8	Possible	–

skeletal soft tissue infection. We sought to determine the confidence with which abscess formation could be diagnosed on DWI in combination with other unenhanced imaging in comparison to the post-contrast sequences.

Materials and methods

Patients

Research ethics board approval was granted and informed consent was waived for this case series. A radiological database search was performed to find cases of skeletal soft tissue infection imaged with MRI including DWI. There were eight patients identified who underwent MRI for suspected skeletal soft tissue infection, including seven patients with contrast-enhanced imaging. One dialysis-dependent patient did not receive intravenous gadolinium due to the risk of nephrogenic systemic fibrosis (NSF) in this patient population. The standard of reference for determining the presence of abscess was the final clinical diagnosis, which was based on a combination of clinical and/or imaging follow-up, surgical or image-guided aspiration/drainage findings, response to antibiotic therapy, histological findings, and culture of an organism (Table 1).

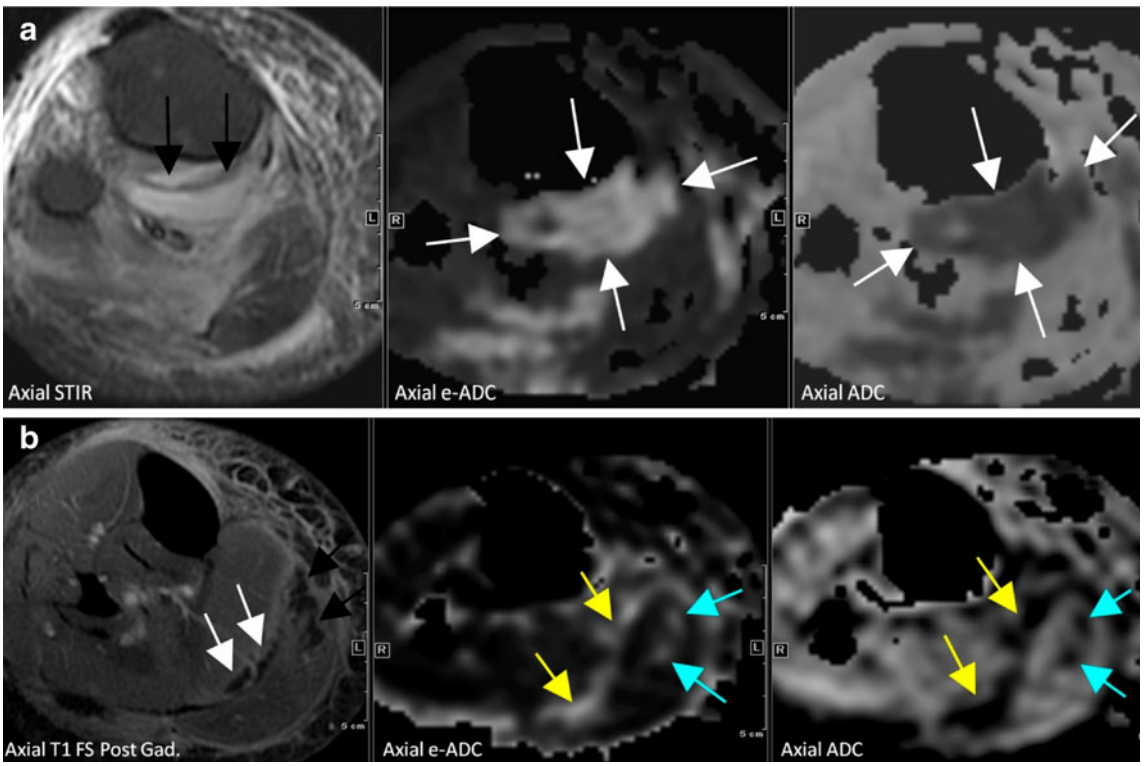

Fig. 1 **a** (case 1): Axial STIR image through the right calf demonstrates extensive edema involving the posterior compartment and subcutaneous tissues and a focal fluid collection posterior to tibia (*black arrows*), which shows high signal on e-ADC (*white arrows*) and hypointensity on the ADC map (*white arrows*) in keeping with restricted diffusion due to abscess formation. **b** (case 1): Axial T1-weighted fat-suppressed post-contrast image shows ill-defined hypointense foci with mild peripheral enhancement in the medial gastrocnemius (*black arrows*) and between the gastrocnemius and soleus (*white arrows*). The surgically proven pockets of pus, shown as high signal on e-ADC and hypointensity on the ADC map in the medial gastrocnemius (*blue arrows*) and between gastrocnemius and soleus (*yellow arrows*), are slightly more conspicuous on DWI than on post-contrast images

MRI technique

All MR images were performed on a 1.5-T magnet (Signa, GE Healthcare). Because of the variation in sites imaged, the technical parameters and coils used varied depending on the site of interest. An eight-channel body array coil was used in seven patients and the TR foot PA coil in one patient. Axial DWI was performed with a single-shot spin-echo echo planar imaging sequence with gradients in three orthogonal planes using b values of 0 and 600 s/mm^2; TR/TE range 1,800–10,000/60–100, 128 × 128 matrix, 26–40-cm field of view, NEX of 8–16, 5–6 mm slice thickness, and 0–1 mm gap (approximate imaging time: 2 min). Apparent diffusion coefficient (ADC) and exponential apparent diffusion coefficient (e-ADC) maps were created. Other unenhanced sequences obtained included a combination of multiplanar fast spin echo (FSE) T1-weighted, T2-weighted, T2-weighted fat-suppressed and STIR sequences. Images obtained after administration of contrast medium in seven patients included spin echo T1-weighted fat-suppressed images and/or 3D fat-suppressed SPGR sequence in one or two orthogonal planes. A dose of 0.1 mmol/kg of intravenous Gadobutrol (Gadovist, Bayer Schering Pharma) was used as the contrast medium.

Image evaluation

The images were reviewed in consensus by two fellowship-trained radiologists. The reviewers were aware of the information that MRI was done to exclude soft tissue abscess. The reviewers assessed the unenhanced MR images, including the DWI sequences. The confidence in diagnosing the presence of abscess was noted on a semi-quantitative Likert scale as "definite," "likely," "possible," "unlikely," and "very unlikely". The contrast-enhanced images were then viewed, where available, and a final assessment was made. The reviewers also noted if DWI increased the diagnostic confidence for detecting abscess. The evaluations were compared against the reference

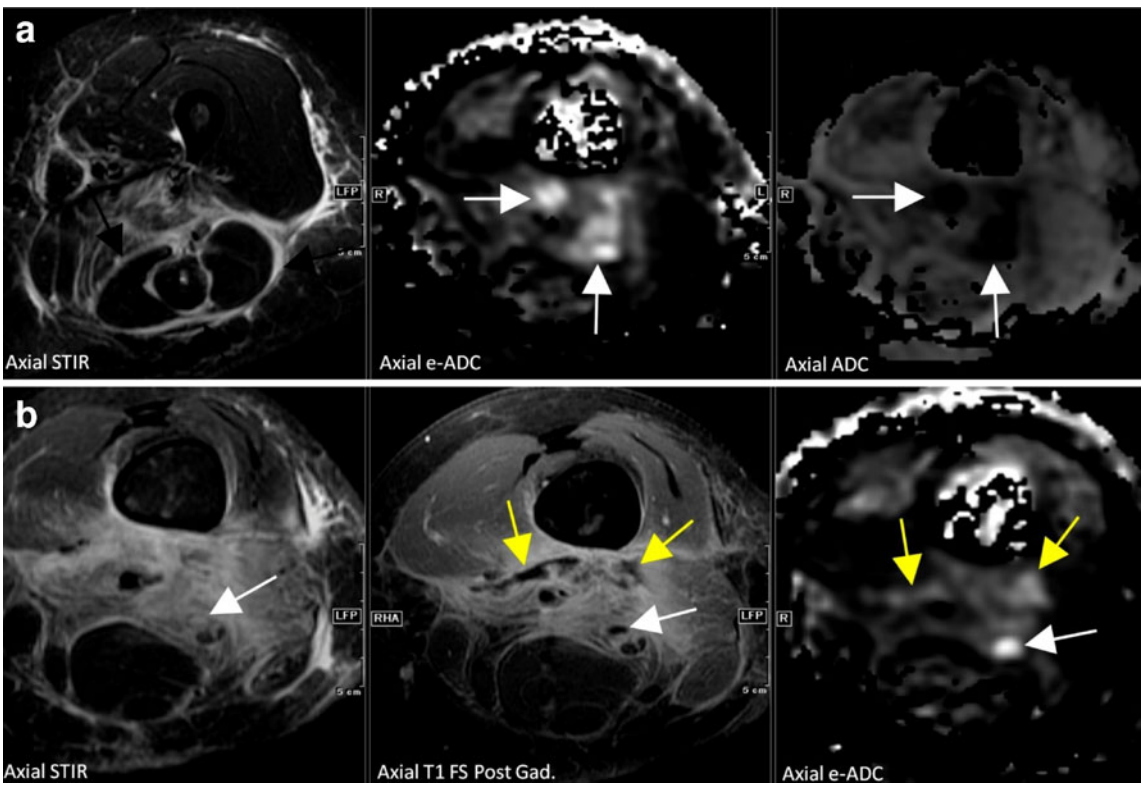

Fig. 2 **a** (case 2): Axial STIR MR image demonstrates extensive hyperintensity of the fasciae (*black arrows*). There is intermuscular edema without a discrete fluid collection. There are e-ADC hyperintense (*white arrows*) and ADC hypointense (*white arrows*) intermuscular foci in keeping with restricted diffusion. **b** (case 2): Axial STIR image shows intermuscular edema and a small fluid collection (*white arrow*) near the sciatic nerve. Post-gadolinium image shows fascial enhancement and small ill-defined foci of hypointensity with mild peripheral enhancement near the nerve (*white arrow*) and posterior to the femur (*yellow arrows*). Corresponding foci on the e-ADC show bright signal near the nerve (*white arrow*) and posterior to the femur (*yellow arrows*). These were dark on the ADC map (not shown) in keeping with restricted diffusion. The e-ADC maps constructed from the DWI data resulted in the highest confidence in correctly predicting the soft tissue abscesses

standard. The assessments of the DWI including the ADC maps were visual with no quantification of ADC values.

Results

Table 2 shows the consensus evaluations. Eight cases of soft tissue abscess were identified and all showed avid restricted diffusion (Figs. 1–8). DWI increased diagnostic confidence in two cases. In these two patients, the fluid filled foci were small/ill-defined and there was only mild rim enhancement around them on the post-contrast images (Figs. 1, 2). Presence of restricted diffusion helped suggest a diagnosis of pyomyositis rather than infectious myositis in case 1 and infectious fasciitis with intermuscular abscesses rather than just infectious fasciitis in case 2. In four cases, the combination of DWI and other unenhanced imaging provided the same confidence levels as the post-contrast images for detecting abscesses. Of these, in three cases (cases 3, 4 and 6) the confidence level was "definite" and in one case it was "likely" (case 7). In cases 3, 4 and 6, the DWI images could be almost exactly correlated to the post-contrast and fluid-sensitive sequence appearance of the abscess (Figs. 3, 4, 6). In one patient (case 7), the only chronic abscess in the series, restricted diffusion helped favor an abscess over a necrotic neoplasm (Fig. 7). In one patient (case 5), the post-contrast images were more useful in suggesting abscess formation, and the DWI showed restricted diffusion in only part of the abscess (Fig. 5). In a single patient (case 8), contrast medium could not be administered as the patient was on dialysis, however, a small poorly-defined fluid collection restricted diffusion (Fig. 8), which was proven to represent abscess at surgery.

Discussion

In the evaluation of musculoskeletal soft tissue infection, it is recognized that gadolinium may not necessarily add value in the diagnosis of infection and in demarcating the amount of disease, but does help in the detection of abscesses [4, 12, 13, 19, 20]. Detection of abscesses with certainty influences management leading to surgical or image-guided drainage [3, 4, 8, 12, 13]. In five cases in the presented series, DWI in conjunction with other unenhanced MR images gave as much information as gadolinium-enhanced sequences. In two cases, DWI was more suggestive for abscess formation than enhanced images. In one case, where intravenous contrast medium could not be administered due to a contraindication, DWI localized the abscess. On the basis of these findings, we suggest that DWI is a useful adjunctive sequence for MR imaging of skeletal soft tissue infection. In pertinent cases, where discrete, large fluid collections are seen in the clinical setting of fever and leukocytosis, a confident diagnosis of skeletal soft tissue abscess could be made based on DWI restriction, and may perhaps obviate the need for contrast material. DWI can be helpful if used in conjunction with post-contrast sequences, when the clinical history is equivocal for infection. For patients with moderate to end-stage kidney disease and those with acute kidney injury, the American College of Radiology (ACR) recommends refraining from administering any gadolinium-based contrast agents because of the risk of developing NSF [21]. When gadolinium is contraindicated, DWI is a vital adjunct to routine unenhanced MR imaging to detect abscess formation.

DWI measures microscopic movement of water molecules in tissues. Water molecules tend to move in a less restricted

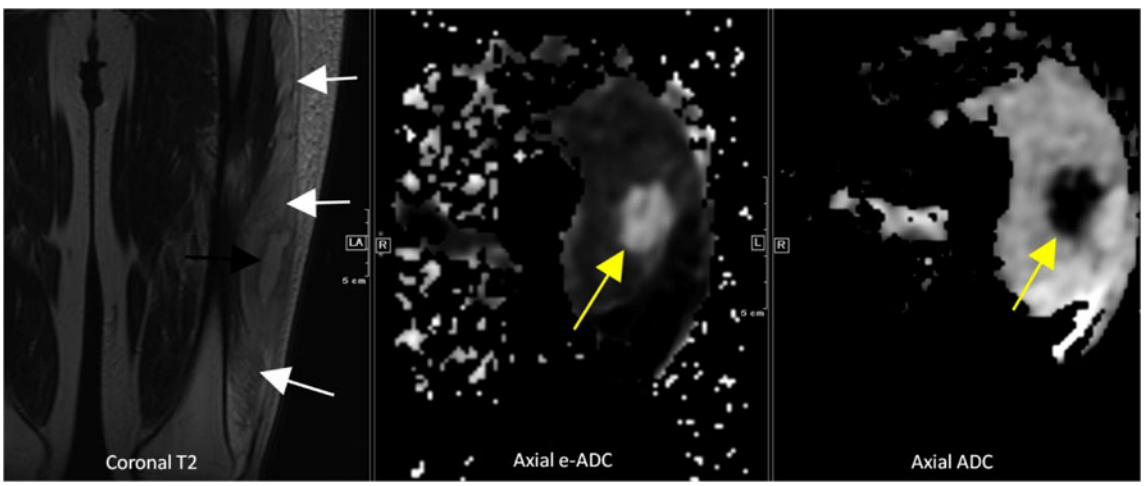

Fig. 3 (Case 3): Coronal T2-weighted MR image through the thigh demonstrates diffuse/extensive edema in the vastus lateralis (*white arrows*) along with an elongated intramuscular fluid collection (*black arrow*). The fluid collection is e-ADC hyperintense (*yellow arrow*) and ADC hypointense (*yellow arrow*) in keeping with avid restricted diffusion. The avid restricted diffusion in this intramuscular abscess allowed a confident diagnosis comparable to gadolinium-enhanced images and provided identical spatial localization and volume of pus

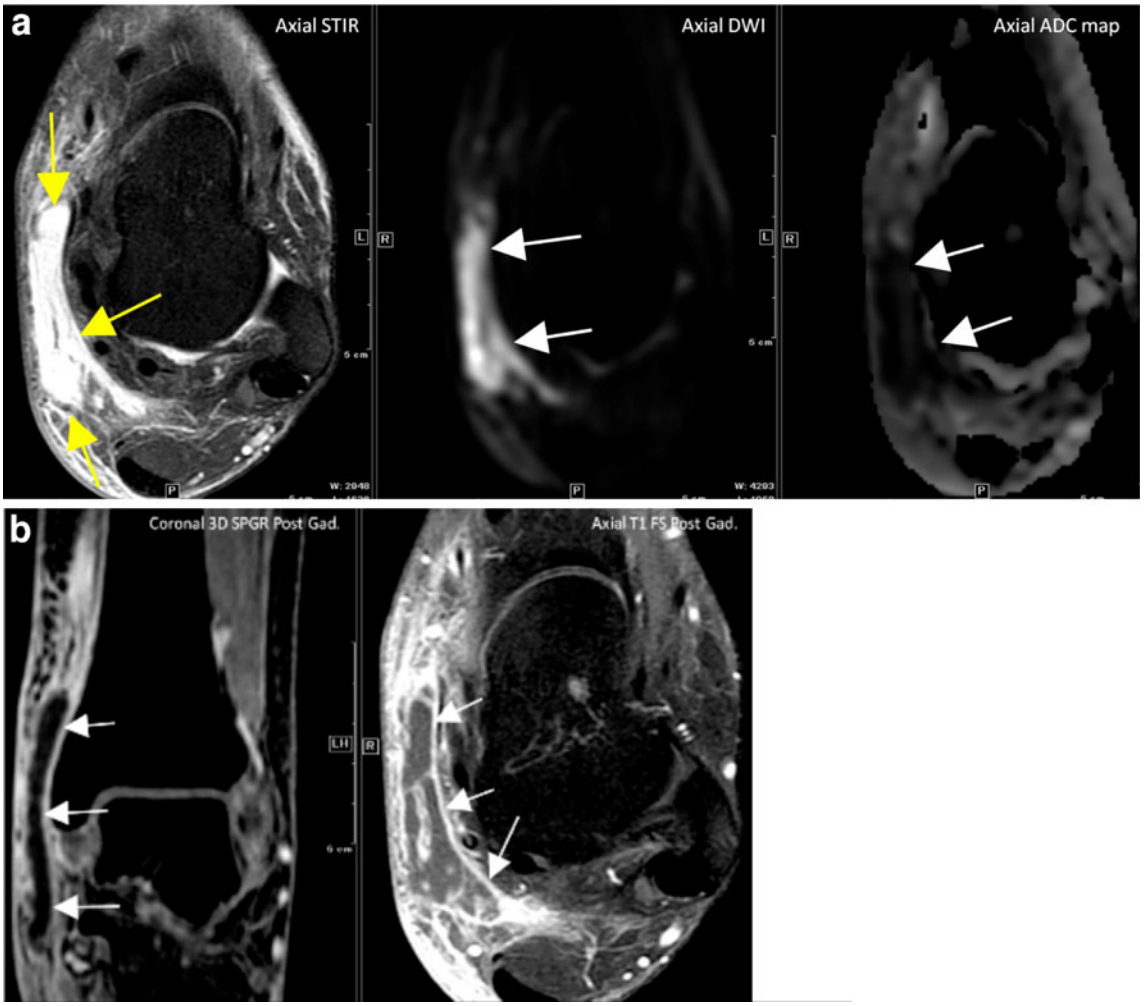

Fig. 4 **a** (Case 4): Axial STIR MR image showing extensive subcutaneous edema along the medial aspect of the ankle along with tubular foci of brighter signal in keeping with focal fluid collection (*yellow arrows*). The fluid collection is DWI bright (*white arrows*) and ADC dark (*white arrows*) in keeping with avid restricted diffusion. **b** (Case 4): Coronal and axial post contrast MR images demonstrate peripheral enhancement around the elongated medial subcutaneous fluid collection (*white arrows*). Both DWI and post-contrast images afforded the same confidence levels in the diagnosis of this subcutaneous abscess

fashion in the extracellular space compared to the intracellular location. Any process that impairs the free flow of water, leading to a decrease in extracellular water content, will lead to a DWI signal abnormality [14, 22]. Abscesses contain inflammatory cells, a matrix of proteins, cellular debris, and bacteria in high-viscosity pus; all of these factors restrict water motion. This feature of abscess formation allows its detection using DWI with restricted diffusion characterized by high signal intensity on DWI and decreased ADC values.

Restricted diffusion in a soft tissue lesion is by no means specific for abscess. Tumors with high cellularity can show restricted diffusion [23]. However, confusion of abscesses with neoplasms is less likely to occur if imaging findings are interpreted in the appropriate clinical context. Also, high cellularity tumors that restrict diffusion would tend to show internal contrast enhancement as opposed to abscesses, which show peripheral enhancement. Diabetic patients at risk for skeletal soft tissue abscesses are also at risk for developing myonecrosis. It is uncertain if myonecrosis would restrict diffusion with no reports of this in the literature. However, diabetic myonecrosis tends to have a more classic presentation with relative rapid onset of severe pain in the involved muscles and patients tend to be afebrile [3, 6, 10]. Other diagnoses cannot be ruled out on the basis of DWI features alone, and clinical correlation and/or histological/microbiological confirmation may ultimately be required [4].

Before it liquefies, soft tissue infection is referred to as phlegmon or infectious myositis depending on the anatomical location [3]. With continued inflammation, walling-off occurs, resulting in abscess formation. An important point to consider is that as an abscess continues to mature, it may not restrict on DWI. Abscesses that contain macromolecules will have a low ADC; while on the other hand, abscesses that principally have watery/liquid content will tend to show

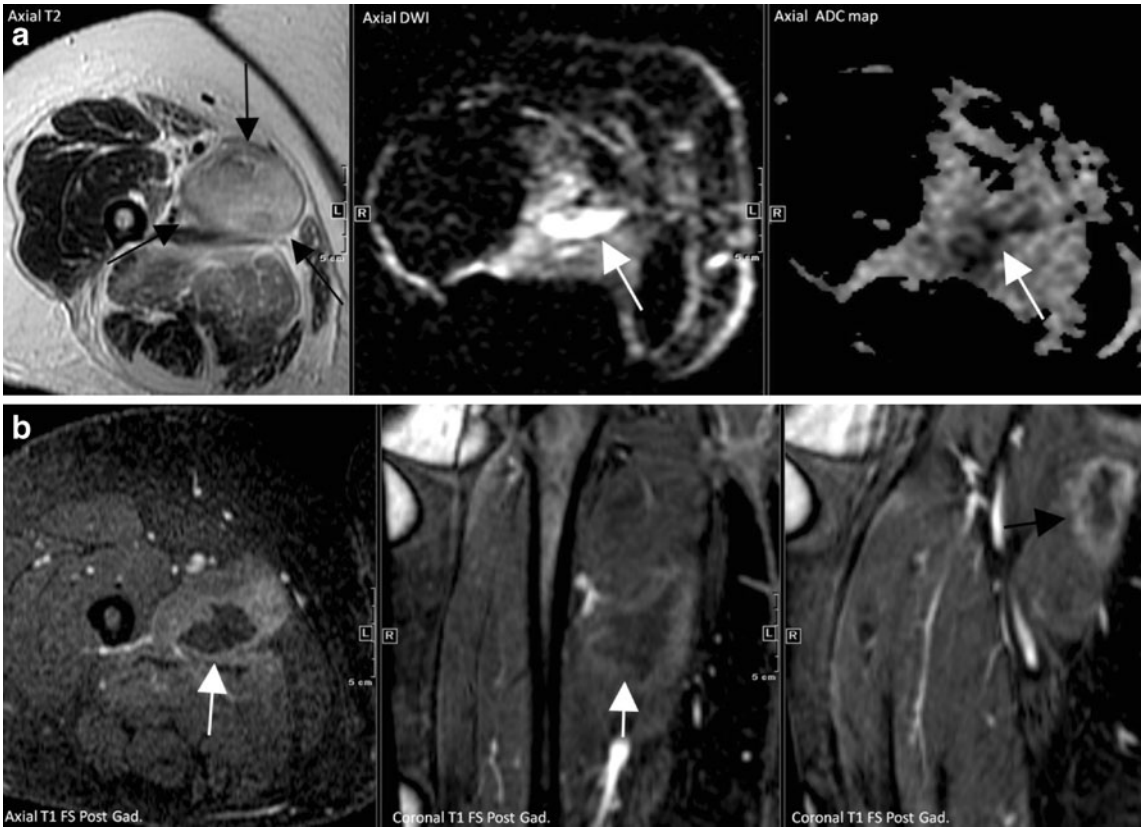

Fig. 5 **a** (Case 5): Axial T2-weighted MR image shows marked edema in the adductor muscles (*black arrows*). There is a DWI bright (*white arrow*) and ADC dark (*white arrow*) focus within the muscle in keeping with restricted diffusion. **b** (Case 5): Axial and coronal post-contrast MR images demonstrate peripheral enhancement (*white arrows*) in the diffusion restricting focus in the mid adductor longus. Note proximal extension of the abscess in the adductor longus (*black arrow*). The rim enhancement was felt to be more predictive of abscess than DWI in this case

a high ADC [16]. When completely liquefied, abscesses could lose the phenomenon of 'restriction of diffusion' due to allowance of more random motion of water molecules. During the process of abscess maturation, the central areas liquefy, and 'T2 shine-through' replaces restriction of diffusion. It is this wide range of diffusion capacity caused by different components that make up an abscess in its evolution that has led some authors to suggest that DWI appears not to be helpful in the assessment of abscesses [16]. However, based on this case series, we contend that DWI has its utility in assessing soft tissue infections/abscesses despite its limitations. In addition, with a fast imaging time of approximately 2 min, the cost and time impact of supplementing DWI to the conventional sequences is insignificant compared to its potential contribution [24].

DWI has been utilized in neuroimaging to identify acute infarction, characterize certain tumors, and help distinguish necrotic neoplasm from brain abscess and assessment of orbital abscesses [24–27]. It has been shown to have a high diagnostic value in differentiation of cysts and abscesses in different parts of the body, particularly in the head and neck [18]. In musculoskeletal radiology, DWI has been used to assess the response of tumors to therapy, differentiate residual tumor from necrosis, distinguish pathologic from benign vertebral body compression fractures, diagnose vertebral osteomyelitis and epidural abscess, and identify active changes in inflammatory arthritis [14, 16, 17, 28, 29]. DWI has also shown to be helpful in evaluating muscle involvement in inflammatory myositides including assessing disease progression and monitoring treatment response [30]. The restricted diffusion in inflammatory myositis is mild and better assessed quantitatively. In contrast, there is usually more avid restriction of diffusion within pockets of pus in skeletal soft tissue abscesses obviating the need for quantifying ADC values.

Technical challenges exist with DWI in the skeletal system and imaging parameters must be adjusted to account for decreased SNR, susceptibility artifact, and motion artifact from patient movement and arterial pulsation [14, 16]. DWI in the skeletal system can be improved by shortening the acquisition time by using a single reference slice and decreasing the slice matrix, decreasing the strength of the diffusion gradient to 500 to 1,000 s/mm^2, and using proper restraint and avoiding large vessels when possible [16].

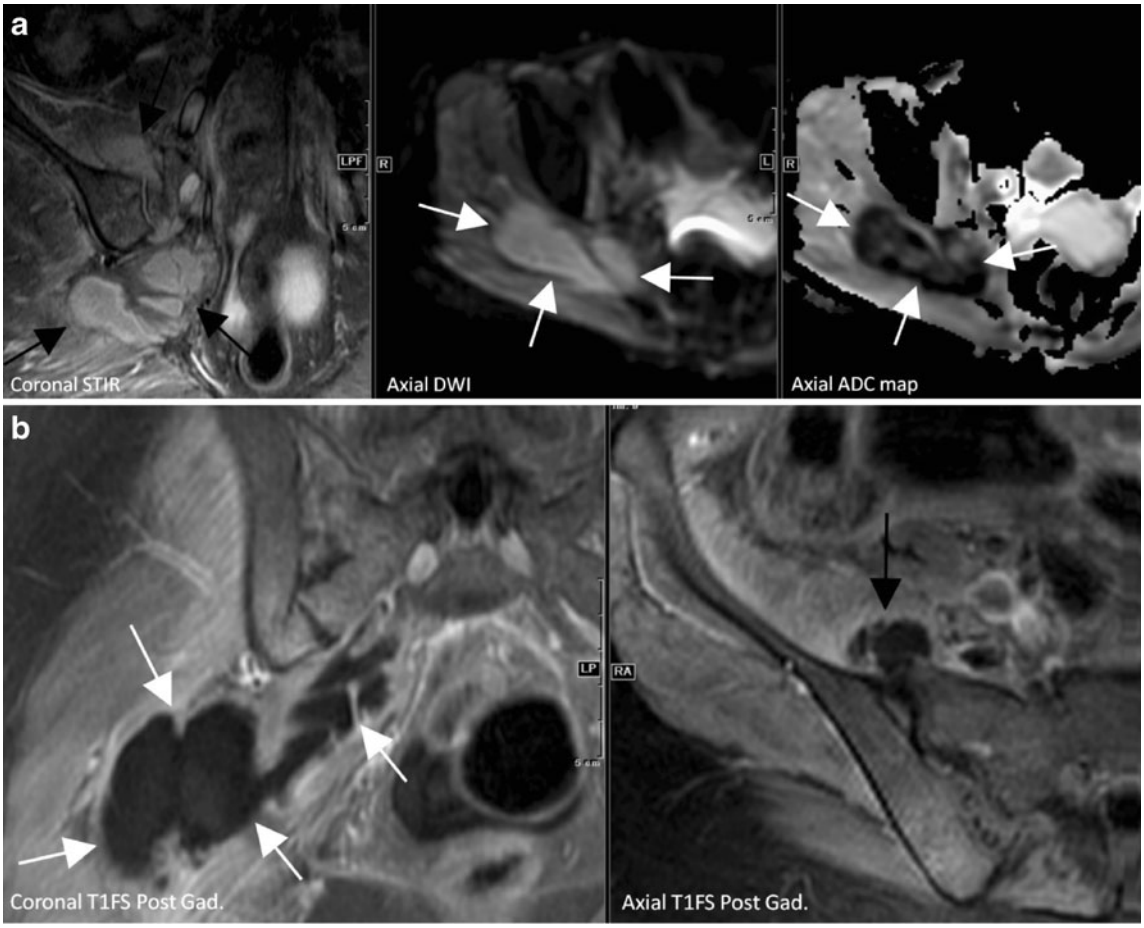

Fig. 6 **a** (Case 6): Coronal STIR MR image showing large fluid collection (*black arrows*) emanating from the right SI joint and reaching the gluteal region through the sciatic notch. The fluid collection is DWI bright (*white arrows*) and ADC dark (*white arrows*) in keeping with avid restricted diffusion. **b** (Case 6): Coronal and axial post-contrast MR images demonstrate peripheral enhancement (*white arrows*) in the large abscess arising from the right SI joint (*black arrow*)

Limitations of the study include the relatively small number of patients. This precludes evaluation of the true accuracy of the technique. The way in which factors such as the degree of viscosity, chronicity, causative organism, and level of protein in the abscess may affect DWI findings cannot be evaluated in this group. A larger series would

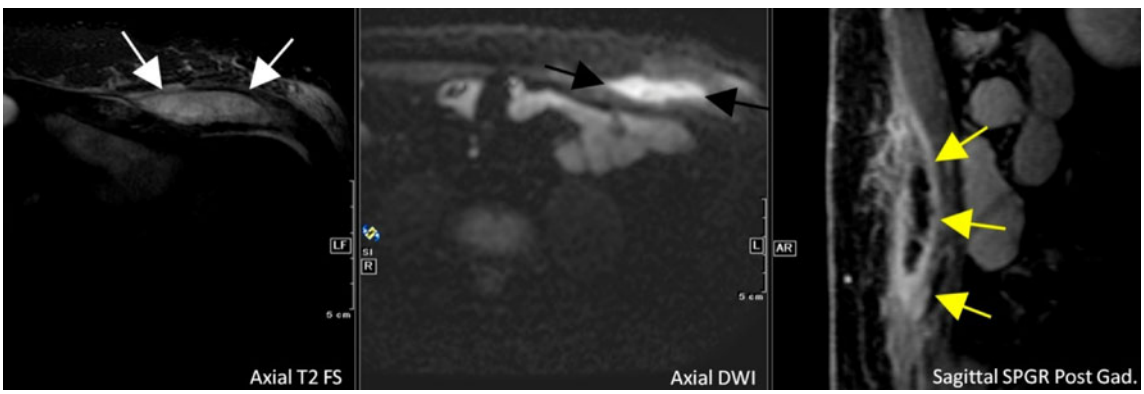

Fig. 7 (Case 7): Axial FSE T2 FS MR image showing a heterogeneously hyperintense mass-like lesion (*white arrows*) within the left external oblique muscle. DWI image shows the lesion to be markedly bright (*black arrows*), and this was hypointense on the ADC (not shown) in keeping with restricted diffusion. Post-contrast MR image shows avid peripheral enhancement around the lesion (*yellow arrows*). DWI and post-gadolinium images were comparable in their ability to predict this chronic intramuscular abscess

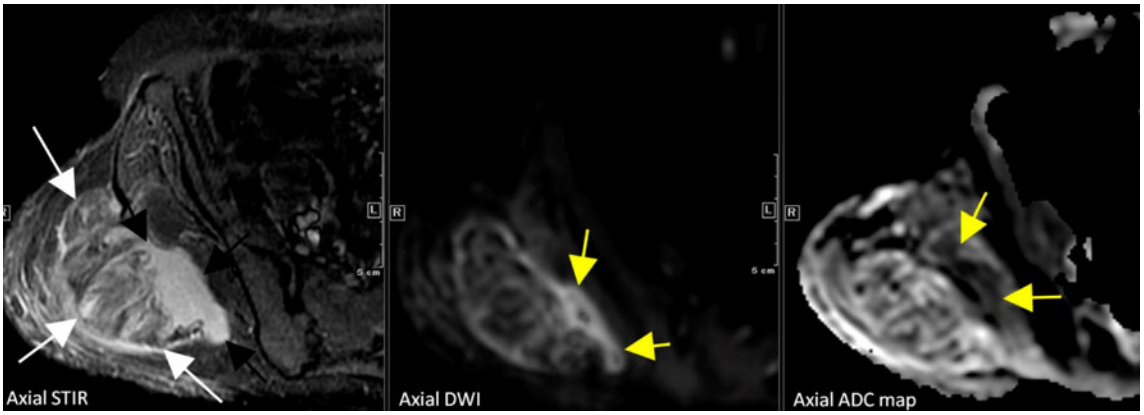

Fig. 8 (Case 8): Axial STIR MR image shows edematous subcutaneous fat in the right gluteal region (*white arrows*) and a deep-seated small ill-defined fluid collection (*black arrows*). This fluid collection restricts diffusion with DWI bright (*yellow arrows*) and ADC dark (*yellow arrows*) signal. Gadolinium was not administered as the patient was on dialysis. Surgical debridement was performed on the basis of the unenhanced and DWI images, which allowed localization and diagnosis of this deep abscess

allow a more thorough comparison of the performance of DWI against contrast-enhanced MRI in the delineation of skeletal soft tissue abscess formation. We did not quantitatively calculate apparent diffusion coefficients as another useful comparison of DWI characteristics; this is more appropriately done in a larger series.

Conclusions

Although the relative small size of the study group limits the conclusions that can be made, our preliminary experience suggests that DWI, with its quick acquisition time, is a valuable adjunct in the MRI evaluation of skeletal soft tissue infections. Where intravenous gadolinium is contraindicated such as in patients with renal failure, DWI may prove beneficial in characterizing fluid collections to suggest abscess formation with more certainty. A prospective MRI study with a larger number of skeletal soft tissue infections in different stages of evolution imaged with DWI and post-contrast imaging is needed to make stronger conclusions.

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