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Added value of diffusion-weighted imaging to conventional MRI for predicting fascial involvement of soft tissue sarcomas

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Abstract

Objectives This study was conducted to evaluate the added value of diffusion-weighted imaging (DWI) to conventional magnetic resonance imaging (MRI) for predicting fascial involvement of soft tissue sarcomas located in close proximity to fascial boundaries.

Methods This retrospective study included 29 patients with surgically resected soft tissue sarcomas located in proximity to deep fascia and with a curvilinear tail-like hyperintensity in the adjacent fascia on T2-weighted images. All patients underwent conventional MRI and DWI at 3.0 T and had detailed histologic reports on involvement of fascia. Two musculoskeletal radiologists with 21 and 1 year of experience independently reviewed conventional MRI and conventional imaging with added DWI. Readers scored their confidence for tumor involvement of fascia using a three-point scale. Diagnostic performance (area under the curve [Az]) of the two MRI sets was assessed with receiver-operating characteristic curve analysis.

Result Fascial involvement was present in 22/29 patients (75.9%). Both readers showed improvement in diagnostic performance with the addition of DWI (Az, from 0.545 to 0.792 and from 0.646 to 0.792 for reader 1 and reader 2, respectively). Adding DWI did not improve sensitivity or specificity for either reader ($p > 0.05$). Interobserver agreement for the confidence scores improved from fair to moderate with the addition of DWI (κ, from 0.390 to 0.560).

Conclusions Adding DWI to conventional MRI improved diagnostic performance on prediction of fascial involvement of soft tissue sarcomas located in proximity to fascia, without significant improvement in sensitivity or specificity.

Key Points

- *Adding DWI to conventional MRI improved readers' confidence level for the prediction of fascial involvement of soft tissue sarcomas that are close to the deep fascia.*
- *Addition of DWI also improved interobserver agreement.*
- *Conversely, compared with conventional MRI, adding DWI did not significantly improve the sensitivity or specificity for the detection of fascial involvement.*

Keywords Soft tissue sarcoma · Fascia · Magnetic resonance imaging · Diffusion magnetic resonance imaging

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Abbreviations

ADC	Apparent diffusion coefficient
DWI	Diffusion-weighted imaging
MPNST	Malignant peripheral nerve sheath tumor
MRI	Magnetic resonance imaging
NPV	Negative predictive value
PPV	Positive predictive value
ROC	Receiver-operating characteristic
UPS	Undifferentiated pleomorphic sarcoma

Introduction

Soft tissue sarcomas are a histologically diverse group of tumors of mesenchymal origin, comprising less than 1% of adult malignancies [1]. The primary treatment for soft tissue sarcoma is wide local excision of the tumor with a margin of normal tissue [2]. Magnetic resonance imaging (MRI) is the imaging modality of choice for the evaluation of the local extent of soft tissue sarcomas, with this being critical in determining the surgical margins.

Soft tissue sarcomas tend to grow along the path of least resistance by spreading along the fascial plane and expanding within muscle fibers [3]. Due to the centrifugal growth pattern, the majority of the soft tissue sarcomas form a pseudocapsule, which is composed of an inner layer of fibrous capsule and an outer layer of reactive zone with preexisting normal, compressed connective tissue [4, 5]. However, despite the presence of pseudocapsule, tumor cells may be found beyond the pseudocapsule in 55% of various histologic subtypes of soft tissue sarcomas [4].

Occasionally, soft tissue sarcomas located in close proximity to fascial boundaries, including superficial investing layers of the deep fascia or intermuscular deep fascia, exhibit curvilinear tail-like hyperintensity in the adjacent fascia on T2-weighted images. Possible explanations for these MRI findings would be either infiltrative tumor growth in the fascia, viable cells spreading to the adjacent fascia beyond the pseudocapsule, or true reactive edema. Therefore, it can sometimes be difficult to reliably determine the presence or absence of tumor involvement in the fascia with conventional MRI alone, and it may be problematic in the planning of adequate surgical margins to ensure a negative margin of normal tissue while preserving function and minimizing morbidity.

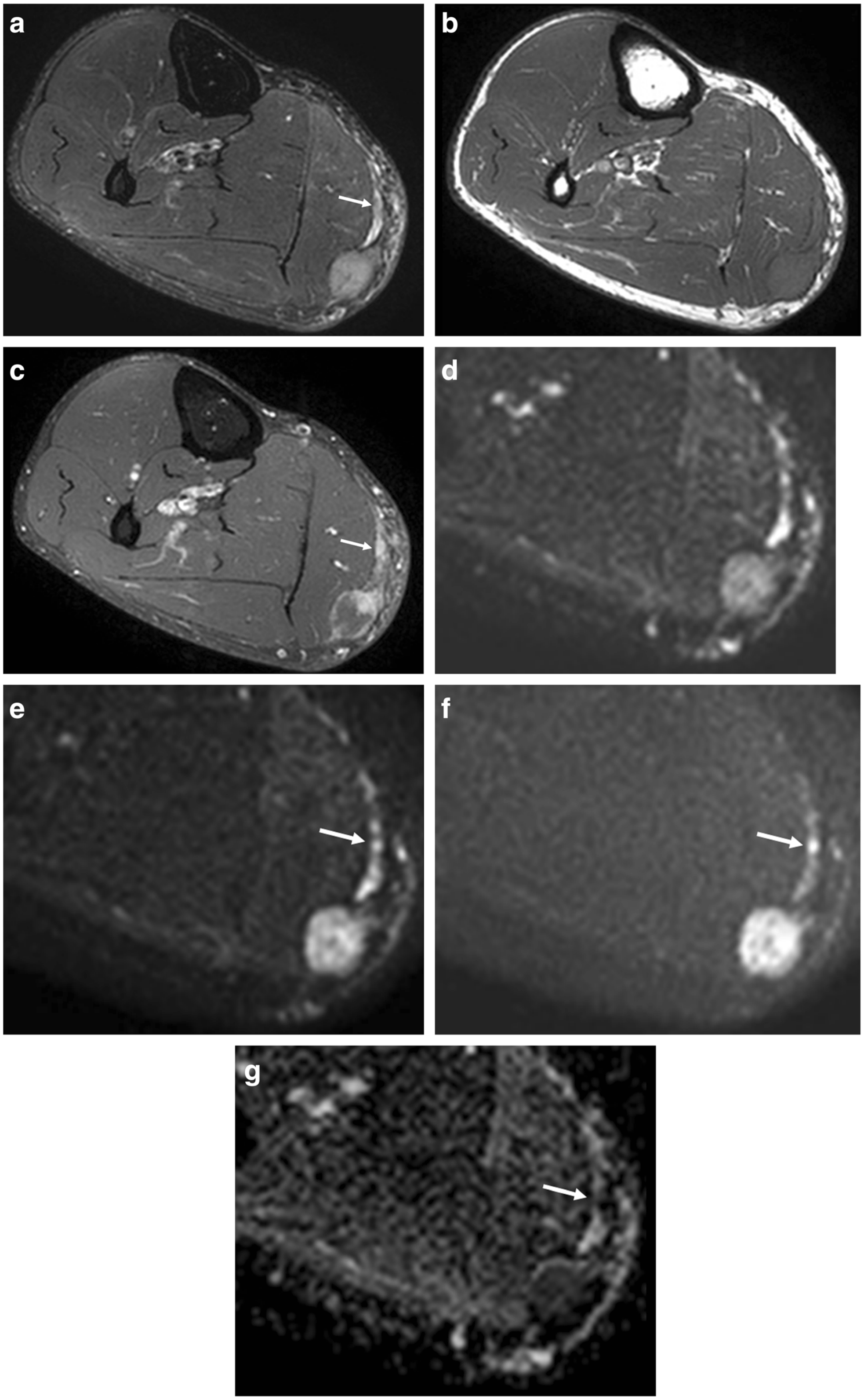
With technical advances in MRI, we postulated that the surgical margin could be more accurately determined if functional sequences were added to morphological imaging sequences. Diffusion-weighted imaging (DWI) is one such widely used functional MR technique, providing information on the mobility of water protons [6], and it has been shown to be useful for assessing the tumor cellularity of soft tissue sarcomas [7]. To our knowledge, no prior studies have evaluated the diagnostic performance of DWI for predicting the fascial involvement of soft tissue sarcomas located in close proximity to fascial boundaries. Therefore, our goal was to evaluate the added value of DWI for predicting fascial involvement in patients with extremity and trunk soft tissue sarcomas, by comparing combined MRI acquisitions with conventional MRI alone.

Materials and methods

Study population

This retrospective study was approved by our institutional review board, and the requirement for informed consent was waived. The hospital database was searched for patients who underwent wide excision for soft tissue sarcomas of the extremities and trunk between January 2013 and June 2018. The inclusion criteria were as follows: (a) preoperative MR examination with a conventional protocol and DWI at 3.0 T; (b) presence of soft tissue sarcomas that had a close spatial relationship (a distance of 2 mm or less) with fascial boundaries, including the superficial investing layer of the deep fascia or intermuscular deep fascia as evaluated on conventional MR images, and with a curvilinear tail-like T2 hyperintensity in the adjacent fascia (Figs. 1, 2, 3, and 4), as determined by a radiologist (M.A.Y.) with 7 years of clinical experience in soft tissue tumor imaging and who was not involved in the image analysis of this study; and (c) detailed surgical and histologic reports on fascial involvement. Of the 162 identified patients who underwent wide excision for malignant soft tissue sarcomas, 133 were excluded for the following reasons: no DWI ($n = 31$); MRI not performed at our center ($n = 16$); inadequate MRI quality ($n = 4$); mass located more than 2 mm away from the fascial boundaries and without a curvilinear tail-like hyperintensity in the adjacent fascia ($n = 25$); no clear mention of fascial involvement on histopathologic reports or tumors located in intercompartmental planes, i.e., areas with no natural compartments such as inguinal or axillary regions or intermuscular planes ($n = 44$); unintended excision performed at outside hospitals ($n = 11$); and time range between MRI and surgery longer than 2 months ($n = 2$). Therefore, the final study population consisted of 29 patients (mean age, 59.2 years; range, 27–82 years), with 19 men (mean age, 56.5; range, 27–79 years) and 10 women (mean age, 64.4 years; range, 27–82 years). The median interval between preoperative MRI and surgery was 16.4 days (range, 1–39 days). The histological diagnoses of the tumors were undifferentiated pleomorphic sarcoma (UPS; $n = 12$),

Fig. 1 A 66-year-old male with pleomorphic rhabdomyosarcoma located in proximity to the superficial investing layer of the deep fascia. **a** An axial fat-suppressed T2-weighted image demonstrates a curvilinear tail-like T2 hyperintensity in adjacent fascia (arrow). **b**, **c** Axial T1-weighted (**b**) and contrast-enhanced fat-suppressed T1-weighted images (**c**) show subtle nodular enhancement within the T2 hyperintense fascia. **d**–**f** DWI with b values of 0 s/mm^2 (**d**), 400 s/mm^2 (**e**), and 800 s/mm^2 (**f**) shows a persistent hyperintense focus (arrow) within the fascia. **g** On the ADC map, the same focus (arrow) demonstrates low values with a similar signal intensity to the main mass. Both readers correctly interpreted as positive fascial involvement (confidence score 3) on both reading sessions. The histopathologic findings showed positive fascial involvement ▶



myxofibrosarcoma ($n = 4$), myxoid liposarcoma ($n = 2$), dermatofibrosarcoma protuberans ($n = 4$), undifferentiated spindle cell sarcoma ($n = 2$), pleomorphic rhabdomyosarcoma ($n = 1$), malignant peripheral nerve sheath tumor (MPNST; $n = 1$), dedifferentiated liposarcoma ($n = 1$), clear cell sarcoma ($n = 1$), and angiosarcoma ($n = 1$). None of the subject had neoadjuvant therapy. Twenty-three masses were located in the extremities (thigh [$n = 12$], upper arm [$n = 5$], lower leg [$n = 4$], and forearm [$n = 2$]), four in the trunk/back, and two in the gluteal region.

Standard of reference

All subjects had detailed histologic reports on tumor involvement of the fascia. Histopathologic analyses were performed by a pathologist (J.S.S.) with 9 years of clinical experience in interpreting soft tissue sarcomas. Positive fascial involvement was defined as infiltrative tumor growth in the fascia or tumor cells spreading through the fascia beyond the pseudocapsule. All surgical procedures were performed by one of two orthopedic surgeons at our institution, J.S.L. and W.K., with 24 and 5 years of experience in soft tissue sarcoma surgery, respectively.

MRI

All patients underwent MR examinations on a 3-T unit (Ingenia or Achieva, Philips Healthcare [$n = 8$ and 16, respectively]; or Magnetom Skyra, Siemens Healthcare [$n = 5$]) with phased-array or extremity coils. The MR sequence parameters varied depending on the anatomic region; however, all of the routine MRI protocols for conventional imaging included axial and either coronal or sagittal T1- and T2-weighted fast spin-echo (FSE) sequences, fat-suppressed T2-weighted FSE sequences in all three planes. All subjects had gadolinium-enhanced fat-suppressed T1-weighted FSE sequences in all three planes.

Before contrast enhancement, DWI was acquired in the axial plane using single-shot echo-planar imaging with fat suppression (spectral attenuated inversion recovery, SPAIR). A parallel imaging technique using sensitivity encoding (SENSE; Philips Healthcare) or generalized autocalibrating partially parallel acquisition (GRAPPA; Siemens Healthcare) with an acceleration factor of 2 was used. DWI was performed using three orthogonal gradient directions and b values of 0, 400, and 800 s/mm^2. Apparent diffusion coefficient (ADC) maps were automatically generated by software on the scanners, with all b values fitted to the following equation:

$$\mathrm{SI}_b = \mathrm{SI}_0 \times e^{(-b\mathrm{ADC})}.$$

The other DWI parameters included echo time, 70–78 ms; repetition time, 3388–5557 ms; flip angle, 90°; matrix, 176 × 176–256 × 256; pixel size, 0.98 × 0.98–2.06 × 2.06 mm^2; and signal averaging, 2–6.

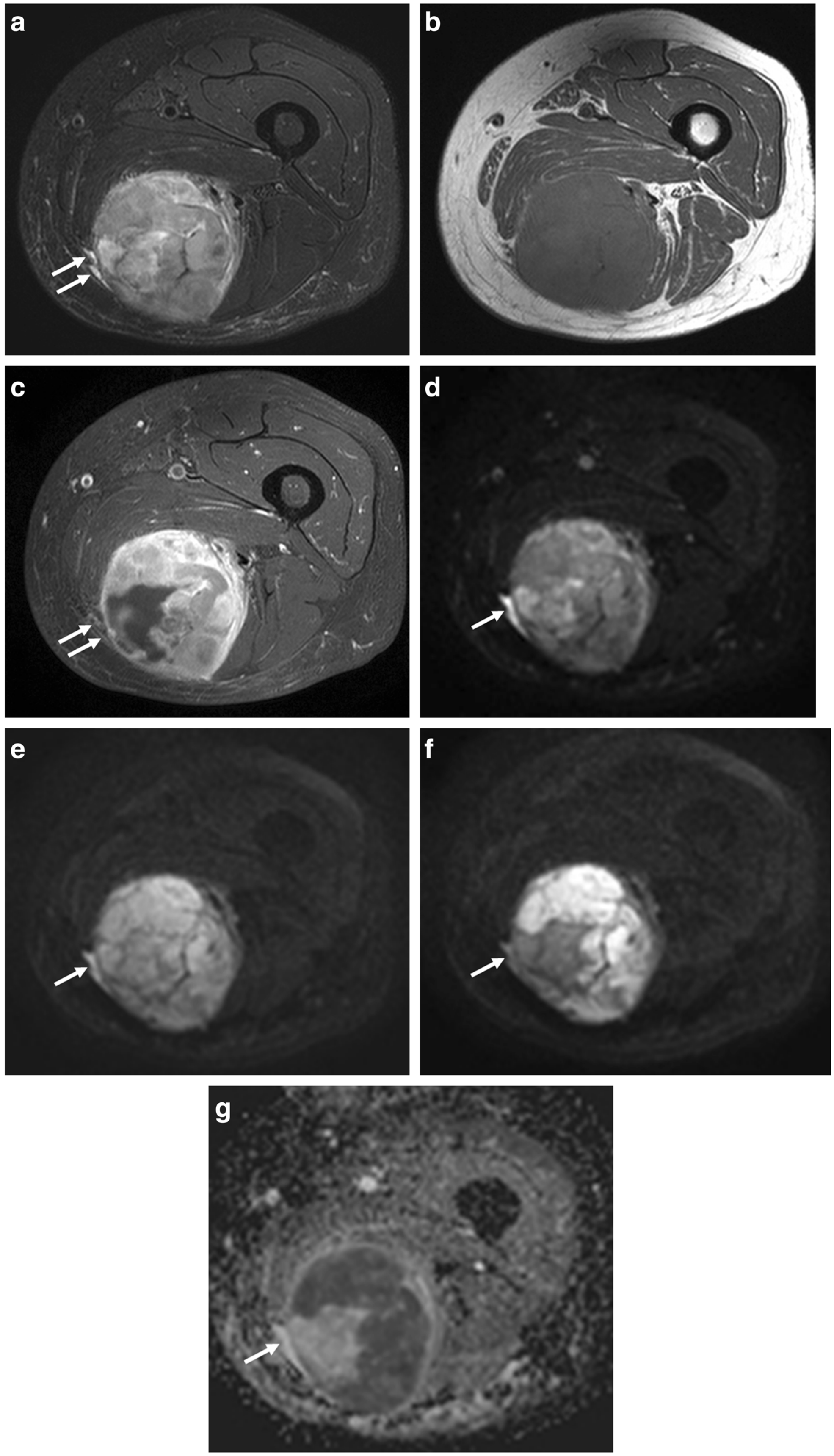
MRI analyses

Two board-certified musculoskeletal radiologists (H.W.C. [reader 1] and C.G.C. [reader 2], with 21 and 1 year of experience in soft tissue tumor imaging, respectively) who were blinded to the histologic findings independently reviewed the two MRI sets (conventional MRI vs. the combined conventional MRI and DWI), separated by an interval of 1 week. As the DWI was acquired in the axial plane, only axial T1- and T2-weighted FSE images, fat-suppressed FSE images, and contrast-enhanced fat-suppressed T1-weighted FSE images were included in the conventional MRI set for this study. For conventional MRI analyses, both nonenhanced and contrast-enhanced images were used altogether in all subjects. All images were reviewed on our institution's picture archiving and communication system (Petavision, Asan Medical Center).

Fig. 2 A 67-year-old female with undifferentiated pleomorphic sarcoma. ▶ **a** An axial fat-suppressed T2-weighted image demonstrates a curvilinear tail-like T2 hyperintensity in adjacent fascia (arrow). **b**, **c** Axial T1-weighted (**b**) and contrast-enhanced fat-suppressed T1-weighted images (**c**) show poorly defined, weak contrast enhancement in T2 hyperintense fascia. **d**–**f** A hyperintense signal seen in the fascia on DWI decreases as the b value increases (**d**, $b = 0$ s/mm^2; **e**, $b = 400$ s/mm^2; and **f**, $b = 800$ s/mm^2). **g** On the ADC map, the fascia represents relative hyperintensity (arrow) compared with the main mass. Based on conventional MRI, both readers interpreted as positive fascial involvement (confidence score 3). However, after the addition of DWI, reader 1 interpreted as equivocal fascial involvement (score 2) and reader 2 interpreted as negative fascial involvement (score 1). The histopathologic findings showed negative fascial involvement

In the first reading session, the readers recorded their confidence level with respect to fascial involvement (superficial investing layer of the deep fascia or intermuscular deep fascia) using a three-point scale based on conventional MRI findings. The three-point scale was as follows: a score of 1 indicated probable negative fascial involvement; a score of 2, equivocal findings; and a score of 3, probable positive fascial involvement. We predefined the presence of fascial involvement as follows: (1) a comparatively wide surface of contact between the mass and the fascia, with the mass forming an obtuse angle to the fascia; (2) the mass extending through the fascia (both superficial and beneath the fascia); (3) nodular or mass-like thickening and enhancement of the fascia; and (4) well-defined, strong curvilinear enhancement of the fascia. MRI findings including slight or no direct contact between the mass, and a relatively thin curvilinear tail-like T2 hyperintensity in the adjacent fascia with the mass forming an acute angle to the fascia, were regarded as being negative for fascial involvement. A mass forming an angle around 90° to the adjacent fascia was regarded as equivocal fascial involvement.

In the second reading session, readers scored their confidence level according to findings on the combined image sets (conventional MRI and DWI). The readers interpreted the presence of persistent high signal intensity in comparison with that of normal skeletal muscle with increasing b values ($b = 0$, 400, and 800 s/mm^2) and a low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signal intensity similar to the solid portion of the primary mass on ADC maps as a sign of positive fascial involvement. Signal intensity changes with increasing *b* value were assessed using three different *b* values, because increasing *b* values reflect tissue cellularity while minimizing perfusion and T2 shine-through effects [8]. DWI, ADC maps, and axial conventional MR images were evaluated side by side to ensure correct matching of the location. When findings on conventional MRI were equivocal or differed from the conventional MRI findings, the readers were asked to give priority to the DWI findings.

In many cases, it was difficult to reliably measure ADC values of the thin fascia with curvilinear tail-like T2 hyperintensity. Therefore, quantitative analyses of the ADC values were not performed.

Statistical analysis

Statistical analyses were performed using the SPSS software package version 16.0 (SPSS).

The diagnostic performance of each reader was assessed using the receiver-operating characteristic (ROC) curve. The area under the ROC curve (Az) was considered to indicate diagnostic accuracy; 95% confidence intervals were used to express the statistical precision of the results.

Diagnostic accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for both readers, on the assumption that a confidence of level of 2 or 3 was positive for fascial involvement. Statistical significance of the observed differences in sensitivity and specificity was evaluated with the McNemar test [9].

The readers scored their confidence for tumor involvement of fascia using a three-point scale.

Interobserver agreement between the two readers for the three-level confidence scores for predicting fascial involvement was assessed with kappa statistics. A κ value of less than 0.20 was taken to indicate poor agreement, a value of 0.21–0.40 as fair agreement, 0.41–0.60 as moderate agreement, 0.61–0.80 as good agreement, and a value of more than 0.81 as excellent agreement [10]. P values < 0.05 were considered statistically significant.

Results

Fascial involvement was present in 22 of 29 subjects (75.9%): UPS, 8/12 subjects were positive for fascial involvement; undifferentiated spindle cell sarcoma, 1/2; pleomorphic rhabdomyosarcoma, 2/2; myxofibrosarcoma, 4/4; myxoid liposarcoma, 2/2; dermatofibrosarcoma protuberans, 3/4; MPNST, 1/1; dedifferentiated liposarcoma, 1/1; clear cell sarcoma, 1/1; and angiosarcoma, 0/1. Only the presence or absence of fascial involvement was assessed, and the exact extent of fascial involvement or the distance between the fascia and the periphery of the tumor was not included in the histological analysis.

Fig. 3 An 81-year-old female with undifferentiated pleomorphic sarcoma. **a** An axial fat-suppressed T2-weighted image demonstrates a curvilinear T2 hyperintensity in the periphery of the tumor near the fascia (arrows). **b**, **c** Axial T1-weighted (**b**) and contrast-enhanced fat-suppressed T1-weighted images (**c**) show enhancement in the T2 hyperintense area. **d**–**f** DWI with *b* values of 0 s/mm^2 (**d**), 400 s/mm^2 (**e**), and 800 s/mm^2 (**f**) shows a persistent hyperintensity (arrows). **g** On the ADC map, the same area (arrows) demonstrates relative low signal intensity. Reader 2 interpreted as equivocal fascial involvement (score 2) with conventional MRI alone but changed as positive fascial involvement (score 3) with the addition of DWI. Reader 1 interpreted as positive fascial involvement on both reading sessions. The histopathologic findings showed positive fascial involvement

The primary tumor stages (T) according to the staging system of the American Joint Committee on Cancer 8th edition [11] were as follows: T1 ($n = 11$), T2 ($n = 13$), T3 ($n = 4$), and T4 ($n = 1$). The tumor characteristics are summarized in Fig. 5.

Diagnostic performance with respect to predicting fascial involvement improved for both readers with the addition of DWI (Az, from 0.545 to 0.792 and from 0.646 to 0.792 for reader 1 and reader 2, respectively) (Fig. 6). Under the assumption that a confidence level of 2 or 3 was positive for fascial involvement, there were no significant differences in sensitivity or specificity between the two MRI sets for either of the readers ($p = 0.500$ and 0.625, respectively, for reader 1, and $p = 1.000$ and 0.625 for reader 2).

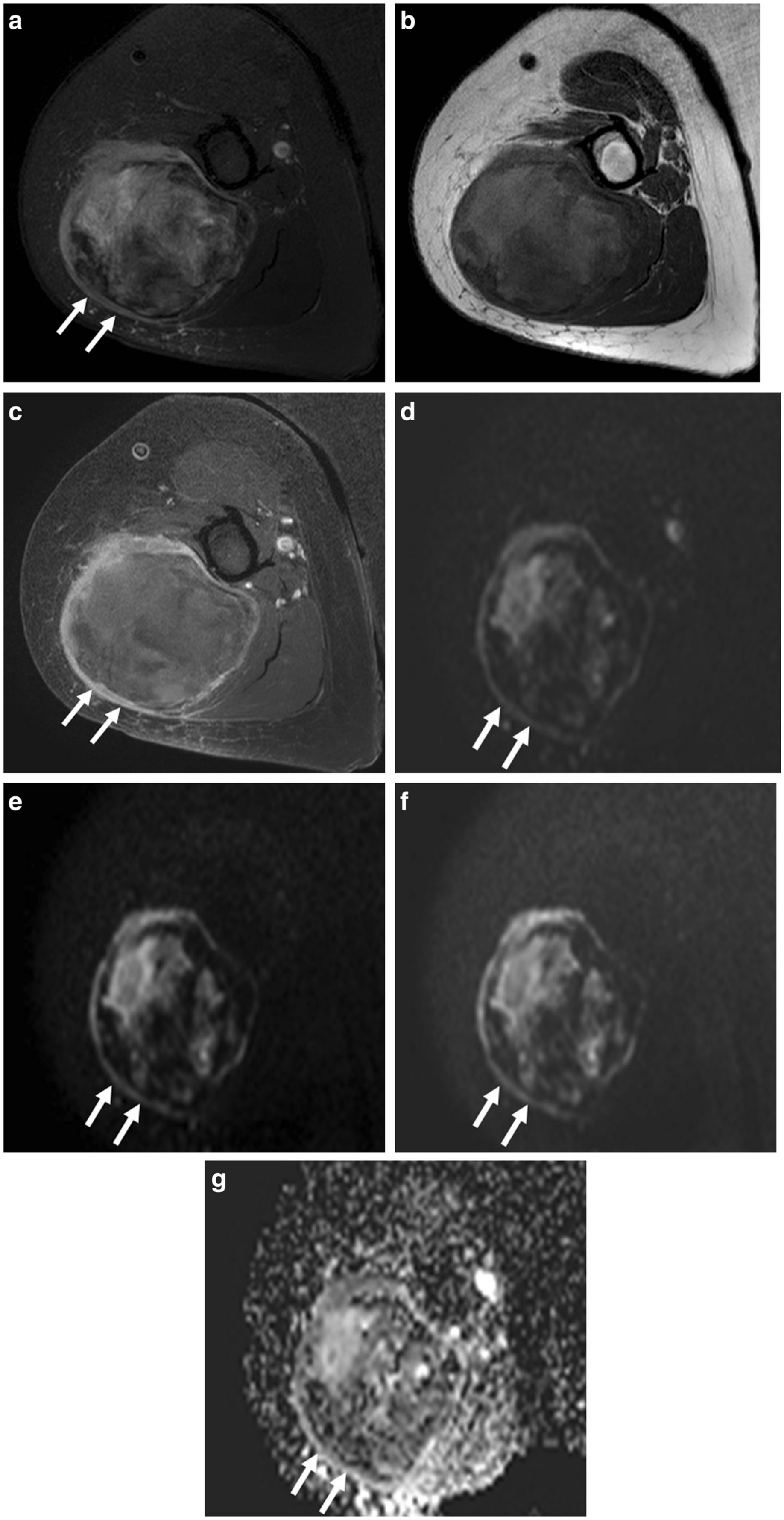
Table 1 shows the diagnostic predictive values for evaluating fascial involvement for each observer and each MRI set.

Interobserver agreements for the three-level confidence scores were fair for the conventional MRI ($\kappa = 0.390$) and moderate for the combined set ($\kappa = 0.560$).

Discussion

In this study, we found that adding DWI to conventional MRI improved readers' confidence level for the prediction of fascial involvement of soft tissue sarcomas using a three-point scale. Moreover, the addition of DWI improved interobserver agreement between the readers of different levels of clinical experience. However, adding DWI did not significantly improve the sensitivity or specificity for prediction of fascial involvement on the assumption that a confidence level of 2 or 3 was positive for fascial involvement.

MRI has been widely used for the evaluation of local tumor extent in soft tissue sarcoma because of its excellent soft tissue contrast [12]. However, it can sometimes be difficult to reliably delineate the true safe margins of soft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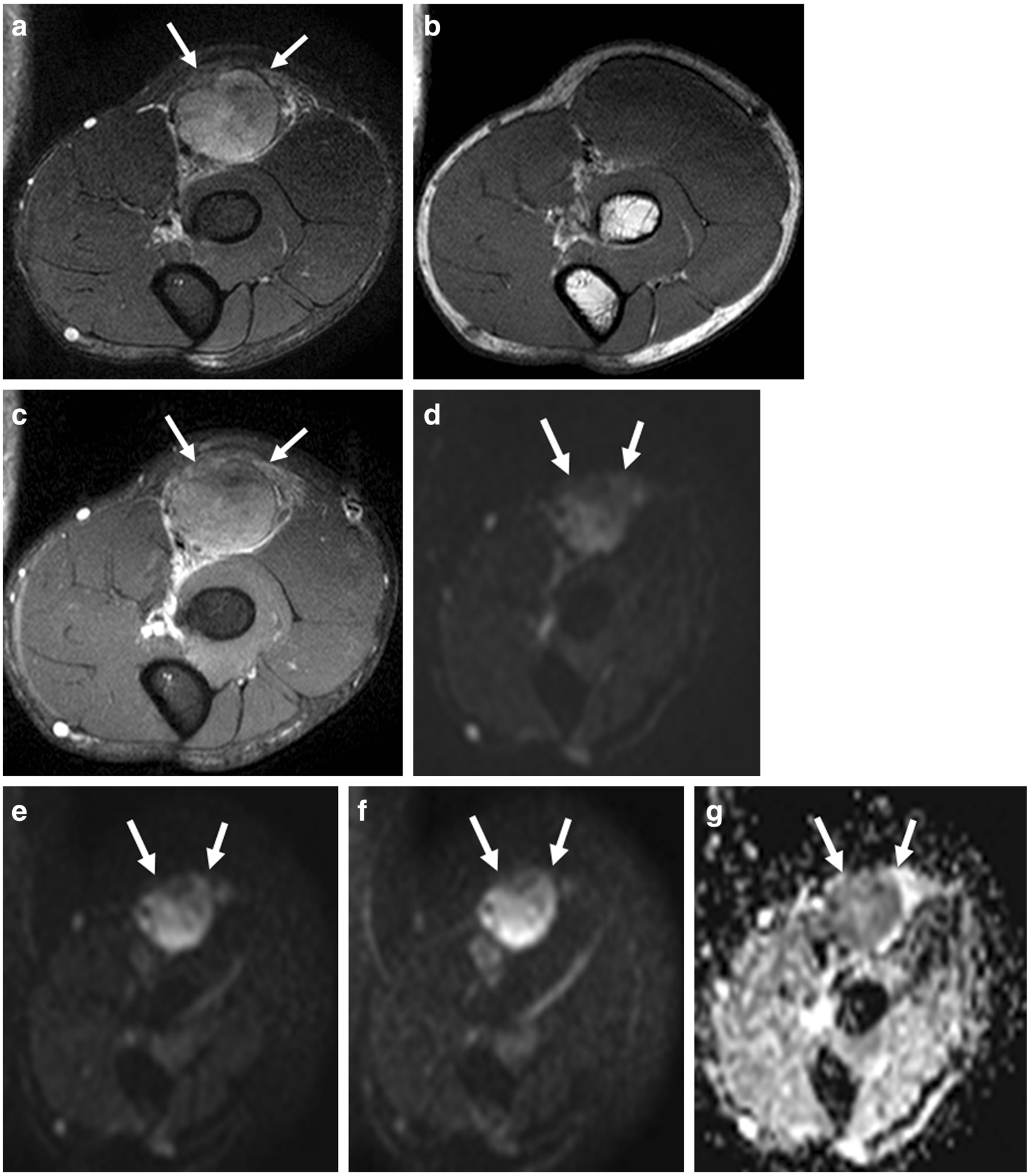

Fig. 4 A 53-year-old male with myxofibrosarcoma. **a**–**c** An axial fat-suppressed T2-weighted image (**a**) demonstrates a curvilinear T2 hyperintensity in the periphery of the tumor near the superficial investing layer of the deep fascia (arrows), and axial T1-weighted (**b**) and contrast-enhanced fat-suppressed T1-weighted images (**c**) show enhancement. **d**–**f** DWI with *b* values of 0 s/mm^2 (**d**), 400 s/mm^2 (**e**), and 800 s/mm^2 (**f**) shows an equivocal signal changes in the fascia as *b* values increase (arrows). **g** On the ADC map, the same area (arrows) demonstrates equivocal signal intensity in the fascia due to suboptimal resolution. Reader 1 scored 3 (positive fascial involvement) based on conventional MRI alone and scored 2 (equivocal) after the addition of DWI. Reader 2 scored 2 (equivocal) based on conventional MRI alone and scored 1 (negative) after the addition of DWI. The histopathologic findings showed positive fascial involvement

tissue sarcomas with surrounding reactive edema in adjacent soft tissue and fascia. The histopathologic characteristics of the "reactive zone" of the soft tissue sarcomas include edema and neovascularity [13], and reactive zones therefore exhibit T2 hyperintensity with contrast enhancement on conventional MRI, signal characteristics similar to those of tumor involvement of the fascia, and which may lead to diagnostic uncertainty. However, the differentiation of reactive edema from tumor involvement in the fascia may be critical in some circumstances, because the normal tissue type surrounding soft tissue sarcomas is one of the major determinants of adequate surgical margins; fat and muscle may require a margin of up to 1 cm, while a margin of 1 to 2 mm may be adequate for fascia [14].

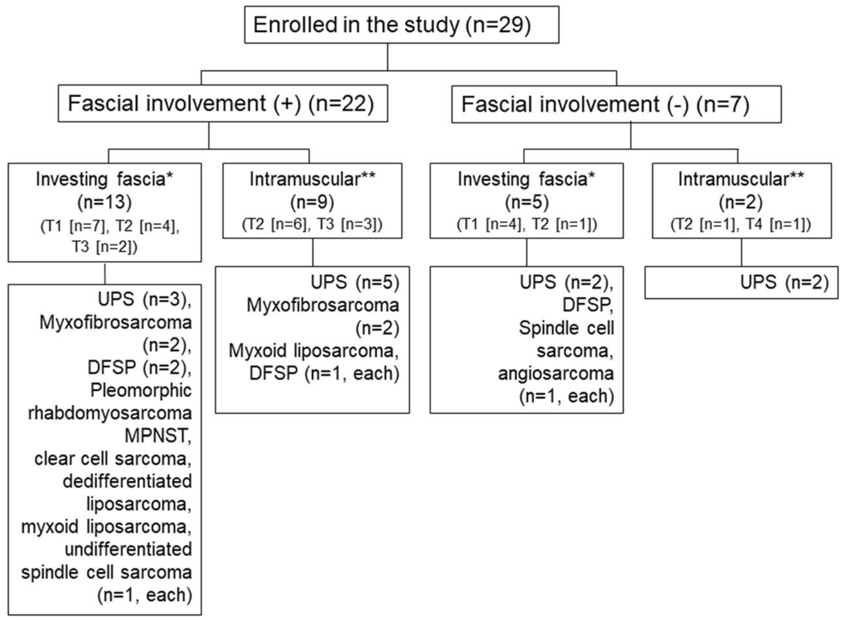

Fig. 5 Subgroup tumor characteristics based on the presence of fascial involvement. * indicates masses mainly located near the superficial investing layer of the deep fascia. ** indicates mainly intramuscular located masses. UPS = undifferentiated pleomorphic sarcoma, DFSP = dermatofibrosarcoma protuberans, MPNST = malignant peripheral nerve sheath tumor

Previous studies described the added value of DWI to soft tissue sarcoma imaging and showed that DWI can aid in the assessment of cellularity and the characterization and differentiation of malignant tumors from benign soft tissue tumors [7, 15, 16]. As DWI provides information on tissue cellularity and cell membrane integrity [17], our initial hypothesis was that DWI would aid in the differentiation of tumor involvement from reactive edema in the fascial boundaries around tumors. Indeed, both readers showed improvement in diagnostic performance after additional review of DWI using the Az of the ROC curve. Tumor infiltration within the fascia showed persistent hyperintensity on high *b*-value DWI and appeared hypointense on ADC maps due to diffusion restriction. Therefore, these imaging findings could help differentiate tumor infiltration from reactive edema, thereby leading to improved diagnostic performance. Moreover, it should be noted that diagnostic performance of conventional MRI in differentiating fascial involvement was poor, as shown by the Az of both readers, reflecting the difficulties in the evaluation of tumor involvement of the fascia in the periphery of the soft tissue sarcomas using conventional MRI alone. This finding is in agreement with a prior study which showed that even tumors with “pushing growth pattern” on conventional MRI had microscopically infiltrative peripheral growth patterns, and MRI failed to identify one third of the tumors that showed an infiltrative growth pattern on histology [18].

In the present study, DWI provided no incremental value for improving sensitivity or specificity for either of the readers, on the assumption that a confidence level of 2 or 3 was positive for fascial involvement. One reason for this

Table 1 Comparison of diagnostic predictive values for evaluation of fascial involvement of soft tissue sarcomas between conventional MRI and combined conventional MRI and DWI

	Az value*	Accuracy (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Conventional MRI only						
Reader 1	0.545 (0.350, 0.741)	69 (20/29)	86 (19/22)	14 (1/7)	76 (19/25)	25 (1/4)
Reader 2	0.646 (0.414, 0.878)	69 (20/29)	77 (17/22)	43 (3/7)	81 (17/21)	38 (3/8)
Combined MRI and DWI						
Reader 1	0.792 (0.596, 0.988)	83 (24/29)	95 (21/22)	43 (3/7)	84 (21/25)	75 (3/4)
Reader 2	0.792 (0.598, 0.987)	79 (23/28)	82 (18/22)	71 (5/7)	90 (18/20)	56 (5/9)
p values						
Reader 1			0.500	0.625		
Reader 2			1.000	0.625		

Note. Numbers in parentheses are raw data. Sensitivity, specificity, accuracy, NPV, and PPV were calculated under the assumption that a confidence score of 2 and 3 was considered positive for fascial involvement

*Data in parentheses are 95% confidence intervals

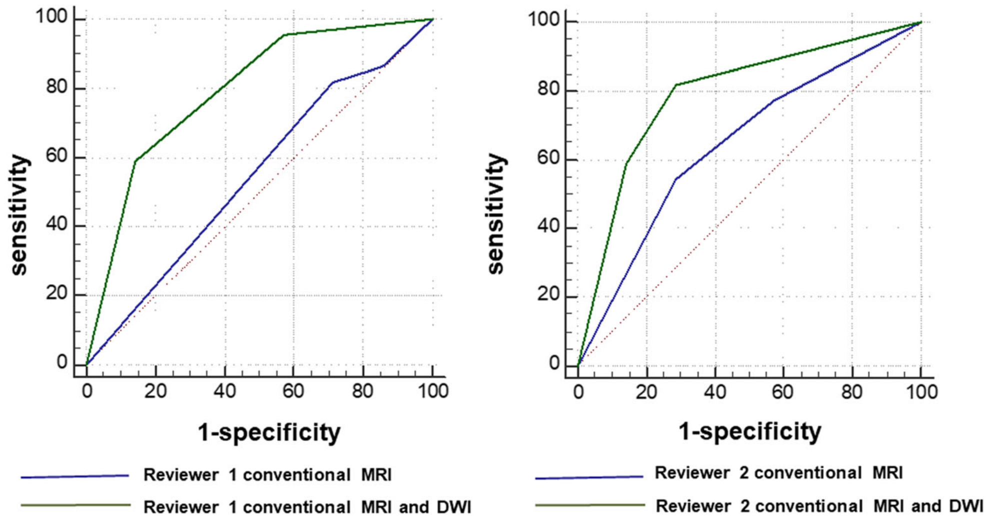

Fig. 6 Receiver-operating characteristic curve of both readers for conventional MRI alone and combined MRI and DWI

result may be the inherent low signal to noise, inferior spatial resolution, and high susceptibility to artifacts of DWI compared with conventional sequences. Importantly, chemical shift artifacts occurring at the interface of subcutaneous fat and muscle, which is in close proximity to the investing layer of the deep fascia, hindered image interpretation in some cases; therefore, DWI had to be used in combination with conventional MRI. Moreover, the difference in the signal averaging (2–6) could have introduced errors in the qualitative evaluation of the fine structures like fasciae. We believe that further improvements in DWI technology and more homogeneous image acquisition may yield additional improvements in diagnostic predictive values. A second reason for the lack of improvement may be the definition of a confidence level of 2 or higher as being positive for fascial involvement. The results could have been different if a different score threshold was used. However, a confidence level of 2 was considered as positive for fascial involvement because equivocal lesions in the imaging of soft tissue sarcomas warrant excision to ensure that adequate margins are achieved. Finally, the relatively high prevalence of positive fascial involvement in our study population could also have affected the results.

The addition of DWI did improve the interobserver agreement between the readers. Only fair interobserver agreement was found between the two readers for conventional MRI alone ($\kappa = 0.390$), thus implying that there were difficulties in differentiating reactive edema from true tumor involvement of the fascia on the basis of contact area and the relative angle between the mass and fascia on conventional MRI alone. By contrast, the addition of DWI to conventional imaging resulted in moderate interobserver agreement ($\kappa = 0.560$), which suggests that the addition of DWI may improve interobserver agreement in the evaluation of fascial involvement of soft tissue sarcomas, especially between readers with different levels of clinical experience.

The prevalence of positive fascial involvement in this study was relatively high (76%), with only about 24% being confined within the subcutaneous fat layer or being purely intramuscular without fascial involvement. Although one reason for this finding may be that we only included soft tissue sarcomas located in proximity to fascial boundaries, this finding is in agreement with those of previous studies showing that only 7% of malignant fibrous histiocytomas were confined to the subcutis [19]. Moreover, in the present study, the proportions of UPS and myxofibrosarcomas, whose infiltrative growth pattern along the fascia has been described in the previous studies [20–22], were relatively high, comprising 55% of the study population. However, this study included a greater variety of histologic subtypes of soft tissue sarcomas, while prior studies focused only on infiltrative growth pattern of myxofibrosarcomas and undifferentiated sarcomas.

This study has several limitations. First, this was a retrospective study with a limited number of subjects. Second, the number of cases with positive fascial involvement was disproportionately larger than the number of negative cases. Third, we only included soft tissue sarcomas located in close proximity to fascial boundaries, including the superficial investing layer of the deep fascia or intermuscular deep fascia, and excluded tumors arising in intercompartmental or intermuscular planes, because in most cases their relationships to fascia or fascial involvement were not clearly mentioned on pathologic reports. Fourth, MRI was performed using three kinds of scanners from two different manufacturers and different types of parallel imaging techniques were used. Thus, the conventional MRI and DWI protocols were somewhat different between them. However, we analyzed the fascial involvement not by quantitative analyses of the ADC values but according to the morphological findings on the imaging, and we believe that the different MR scanners did not influence the analysis of the imaging. Finally, reviewers were blinded to the histologic subtypes during MRI analyses. In clinical standard practice, radiologists are often aware of the histologic subtypes of the soft tissue sarcoma preceding definitive tumor excision, based on either open incisional biopsy or percutaneous core needle biopsy. Therefore, knowledge of histologic subtypes and different growth patterns of specific histologic subtype may also have impacts on the diagnostic accuracy of MRI regarding the fascial involvement and may affect benefits conferred by adding DWI.

In conclusion, the addition of DWI to conventional MRI improved diagnostic performance on prediction of the fascial involvement of soft tissue sarcomas located in close proximity to fascial boundaries without significant improvement in sensitivity or specificity. Further investigation exploring the utility of DWI in defining the exact distance of fascial involvement would be needed to have a direct impact on determining surgical resection margin.

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Compliance with ethical standards

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Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• Retrospective
• Diagnostic or prognostic study
• Performed at one institution

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