Received:
5 November 2015

Revised:
26 January 2016

Accepted:
18 February 2016

<http://dx.doi.org/10.1259/bjr.20150929>

Cite this article as:

Jeon JY, Chung HW, Lee MH, Lee SH, Shin MJ. Usefulness of diffusion-weighted MR imaging for differentiating between benign and malignant superficial soft tissue tumours and tumour-like lesions. *Br J Radiol* 2016; **89**: 20150929.

FULL PAPER

Usefulness of diffusion-weighted MR imaging for differentiating between benign and malignant superficial soft tissue tumours and tumour-like lesions

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Objective: To evaluate the usefulness of adding diffusion-weighted imaging (DWI) with apparent diffusion coefficient (ADC) mapping to conventional 3.0-T MRI to differentiate between benign and malignant superficial soft-tissue masses (SSTMs).

Methods: The institutional review board approved this study and informed consent was waived. The authors retrospectively analyzed conventional MR images including diffusion-weighted images (b -values: 0, 400, 800 s mm⁻²) in 60 histologically proven SSTMs (35 benign and 25 malignant) excluding lipomas. Two radiologists independently evaluated the conventional MRI alone and again with the additional DWI for the evaluation of malignant masses. The mean ADC values measured within an entire mass and the contrast-enhancing solid portion were used for quantitative analysis. Diagnostic performances were compared using receiver-operating characteristic analysis.

Results: For an inexperienced reader, using only conventional MRI, the sensitivity, specificity and accuracy were 84%, 80% and 81.6%, respectively. When combining conventional MRI and DWI, the sensitivity, specificity and accuracy were 96%, 85.7% and 90%, respectively.

Additional DWI influenced the improvement of the rate of correct diagnosis by 8.3% (5/60). For an experienced reader, additional DWI revealed the same accuracy of 86.7% without added value on the correct diagnosis. The group mean ADCs of malignant SSTMs were significantly lower than that of benign SSTMs ($p < 0.001$). The best diagnostic performance with respect to differentiation of SSTMs could be obtained when conventional MRI was assessed in combination with DWI.

Conclusion: Adding qualitative and quantitative DWI to conventional MRI can improve the diagnostic performance for the differentiation between benign and malignant SSTMs.

Advances in knowledge: Because the imaging characteristics of many malignant superficial soft-tissue lesions overlap with those of benign ones, inadequate surgical resection due to misinterpretation of MRI often occurs. Adding DWI to conventional MRI yields greater diagnostic performances [area under the receiver-operating characteristic curve (AUC), 0.83–0.99] than does the use of conventional MRI alone (AUC, 0.71–0.93) in the evaluation of malignant superficial masses by inexperienced readers.

INTRODUCTION

Superficial soft-tissue masses (SSTMs) are a common reason for visiting outpatient clinics. As the availability of radiologic imaging has expanded, the chance of encountering any SSTM for radiologists has also been increased. In the case of some SSTMs, such as lipomas, a definitive diagnosis is not difficult using conventional MRI only because of their characteristic fatty component. However, in much clinical practice, the differentiation between benign and malignant SSTMs using only conventional MRI is problematic, as many of their imaging features are non-specific and some overlap exists between the malignant and benign groups.¹ Diffusion-weighted imaging

(DWI) measures the random motion of water protons in the tissue. The random Brownian motion of water protons determines the DWI signal intensity, and the quantitative assessment of water diffusion in the tissues is expressed as apparent diffusion coefficient (ADC) values. Because of this, the diffusion-weighted (DW) procedure provides a different tissue contrast for the diseased tissue from that attained using conventional MR techniques.^{2,3} Although the usefulness of DWI for assessing soft-tissue tumours have been widely investigated,^{2,4–6} there are not many publications that separately evaluated the usefulness of DWI for SSTMs. The purpose of our study was to retrospectively determine specifically the value of adding

DWI with ADC mapping to conventional 3.0-T MRI to differentiate between benign and malignant SSTMs.

METHODS AND MATERIALS

Patient population

Our institutional review board approved this study and waived the requirement for informed consent.

Since August 2013, MRI that included axial DWI at 3.0 T has been performed for soft-tissue masses at our institution. From August 2013 to April 2015, all of the consecutive patients who underwent MRI with DWI for the evaluation of soft-tissue masses localized to the trunk or extremities were retrospectively evaluated. 232 patients were identified on the initial survey. 138 patients did not undergo histopathological confirmation and were thus excluded from our study. The remaining 94 patients with superficially located lesions were further filtered for image quality, previous excision/surgery and size, as well as pathology indicating lipoma by a radiologist (JYJ) with 2 years' experience in musculoskeletal radiology. SSTMs were defined as lesions located within the subcutaneous fat and superficial to the superficial investing fascia, which separates the subcutaneous tissue layer from the underlying muscle on conventional MRI.^{1,7} 14 patients were excluded owing to image distortion of DWI ($n = 6$), previous treatment such as excision or excisional biopsy ($n = 5$) and lesions <5 mm in maximum diameter, as these were too small to further characterize on conventional MRI ($n = 3$). Patients who had lipomas ($n = 20$) determined on pathologic confirmation were also excluded. Finally, a total of 60 patients [mean age, 48.5 years; age range, 5–80 years; 30 males (mean

age, 47.2 years; age range, 5–80 years) and 30 females (mean age, 49.8 years; age range, 14–71 years)] with SSTMs were included in our study. The detailed histopathological diagnoses are listed in Table 1.

MRI protocols

All examinations were performed on a 3.0-T scanner (Achieva™; Philips Medical Systems, Best, Netherlands) system. Depending on the localization of the tumour, dedicated surface coils were used. The conventional MRI protocols included the axial T_1 weighted turbo spin-echo (TSE) sequence, axial T_2 weighted TSE sequences with and without fat suppression, coronal or sagittal T_1 weighted TSE sequence and coronal or sagittal T_2 weighted TSE sequence with and without fat suppression. In all 60 patients, axial, coronal and sagittal fat-suppressed contrast-enhanced T_1 weighted sequences were also performed. Before the commencement of this diffusion MR study, a series of image quality tests were performed to the adjust acquisition parameters of diffusion and total scan time. A single-shot spin-echo echo-planar DW sequence was performed in axial planes. A parallel imaging technique using sensitivity encoding, or SENSE, was combined with an acceleration factor of 1.5. The echoplanar imaging factor was 67, and sensitizing diffusion gradients were applied sequentially in the x , y and z directions with b -values of 0, 400 and 800 s mm^{-2} .⁸ The ADC maps were automatically calculated using commercial software and were included in the sequences. The sequence parameters are presented in Table 2.

MRI analysis

To assess the added value of DWI in the differentiation of malignant from non-malignant superficial soft-tissue lesions, the

Table 1. Final histological diagnoses of superficial soft-tissue tumours and the number of patients

Benignity/non-malignant	($n = 35$)	Malignant	($n = 25$)
Vascular malformation	6	Malignant melanoma	10
Epidermoid cyst	4	Undifferentiated pleomorphic sarcoma	4
Fibromatosis	3	Fibrosarcoma arising from DFSP	3
PVNS, localized type	3	Malignant peripheral nerve sheath tumour	2
Angioleiomyoma	2	Squamous-cell carcinoma	2
Glomus tumour	2	Clear-cell sarcoma	1
Neurofibroma	2	Lymphoma	1
Nodular fasciitis	2	Myxoid liposarcoma	1
Sarcoidosis	2	Synovial sarcoma	1
Schwannoma	2		
Tumoral calcinosis	2		
Abscess	1		
DFSP	1		
Inflammatory myofibroblastic tumour	1		
Myopericytoma	1		
Organizing haematoma	1		

DFSP, dermatofibrosarcoma protuberans; PVNS, pigmented villonodular synovitis.

Table 2. MR sequence parameters

Parameters	Conventional imaging	Diffusion-weighted imaging
Matrix size	325 × 257–448 × 250	70 × 70–128 × 128
Repetition time (ms)/echo time (ms)	T_1 weighted coronal or sagittal TSE: 456–587/12–20	5000–5200/61–85
	T_2 weighted coronal or sagittal TSE: 2291–2978/60–80	
	T_1 weighted axial TSE: 475–588/15	
	T_2 weighted axial TSE: 2291–2696/80	
Fat suppression	SPAIR	SPAIR
Echoplanar imaging factor	NA	67
Field of view (mm)	Sagittal imaging: 100–300	100–250
	Axial imaging: 80–250	
Section thickness (mm)	1–3	2.5–5
Intersection gap (mm)	0–0.5	0–1
Turbo factor	T_1 weighted imaging: 3	NA
	T_2 weighted imaging: 16	
Number of signals acquired	2	2

NA, not applicable; SPAIR, spectral attenuated inversion recovery; TSE, turbo spin echo.

diagnostic performance of conventional MRI alone and additional DWI with ADC mapping was compared. To evaluate conventional MRI alone, two musculoskeletal radiologists (HWC and JYJ; 19 and 2 years' clinical experience in musculoskeletal MRI, respectively) independently reviewed the conventional MR images of 60 patients, both being unaware of the previous imaging reports and the patients' clinical information, such as histopathological findings or the surgical procedure that was used. SSTMs were interpreted as malignant or non-malignant considering the following imaging features: mass lobulation, fascial oedema, skin thickening, skin contact, haemorrhage or necrosis. An obtuse angle between a mass and the superficial investing fascia and the mass crossing the fascia were also considered as signs suggesting malignancy.^{1,7,9,10} The lesion size was assessed according to the longest diameter measurement. However, the readers did not take the lesion size into account as a significant criterion for differentiating between non-malignant and malignant SSTMs.¹

The same radiologists evaluated the combined sets of conventional MR and axial DWI at least 120 days after the first evaluation in random order. To assess the DWI features of malignant SSTMs, both readers independently analyzed the qualitative signal intensity pattern on DW images and the quantitative ADC value of SSTMs in a blinded fashion.

On qualitative analysis, the signal intensity of SSTMs on DW images using b -values of 0, 400 and 800 s mm^{-2} was classified into three grades, in which grade 0 = signal intensity gradually decreased as the b -value increased, grade 1 = little or no change in signal intensity was shown as the b -value increased and grade 2 = signal intensity gradually increased as the b -value increased.

DWI scans were windowed by the readers to determine the visually optimal level to clearly outline the margin of the mass from the surrounding tissue. We assumed that the lesions would be malignant when visually more increased signal intensity was shown with increasing b -values on DWI.^{4,11}

For quantitative analysis, in the case of inhomogeneous SSTMs, both mean ADC values were obtained from an entire mass ($\text{ADC}_{\text{entire}}$) on one representative axial plane and enhancing solid portion ($\text{ADC}_{\text{solid}}$) that manifested with hyperintense signal on DW images with a high b -value. The ADC value was measured with the use of manually drawn regions of interest (ROIs) on the ADC map, and the average value inside the ROI (mean ADC) was recorded. The region was determined to be the solid portion when it was hyperintense on T_2 weighted images, hypointense on T_1 weighted images and enhanced on fat-suppressed contrast-enhanced T_1 weighted images. $\text{ADC}_{\text{entire}}$ was obtained from the ROI including the entire mass on one axial plane in which the tumour section with the largest diameter on conventional MRI. The most peripheral portion was excluded in order to avoid partial-volume effects.^{4,12} To draw the proper ROI in the representative region of a mass, each reader performed side-by-side comparison between the DW images and the corresponding standard MR images (Figure 1). ADCs were measured with combinations of three b -values (0, 400 and 800 s mm^{-2}). As for the SSTM showing homogeneous enhancement, there was no need to measure separately the ADC value, as there was little difference between $\text{ADC}_{\text{entire}}$ (1380.2 ± 506.8) and $\text{ADC}_{\text{solid}}$ (1325.6 ± 497.5).

Statistical analysis

Statistical analysis was performed using commercial software [SPSS® v. 21 (IBM Corp., New York, NY; formerly SPSS Inc.,

Figure 1. A 68-year-old female with fibrosarcoma arising in the dermatofibrosarcoma protuberans. (a) Axial T_2 weighted (TR/TE, 3111/80) turbo spin-echo MR image of the right inguinal area showing an exophytic well-defined mass involving the skin and subcutaneous adipose tissue. (b) Axial fat-suppressed contrast-enhanced T_1 weighted image (TR/TE, 453/16) demonstrating a lesion with inhomogeneous enhancement. Intratumoral non-enhancement areas, which could indicate intratumoral haemorrhagic cystic degeneration, are seen. The solid enhancing portions are mainly seen in the periphery of the lesion. (c) Axial diffusion-weighted images (TR/TE, 5000/80) with b -values of 0 s mm^{-2} , 400 s mm^{-2} and 800 s mm^{-2} showing a progressive increase of signal intensity within the solid portion (grade 2). (d) Axial apparent diffusion coefficient (ADC) map ($b = 0, 400$ and 800 s mm^{-2}) showing the low mean ADC value of the entire mass ($1284 \mu\text{m}^2 \text{ s}^{-1}$) (arrowhead) and that of the solid portion ($744 \mu\text{m}^2 \text{ s}^{-1}$) (arrow), which was interpreted as a malignant lesion. The far peripheral portion of the mass was not included in the region of interest so as to avoid the partial-volume effect. (e) Photograph of the cut surface of the excised specimen showing a well-circumscribed mass with whitish internal regions (arrows) which are pathologically confirmed as fibrosarcoma and which corresponds to the solid portion of the lower ADC values in (d).

Chicago, IL) and Medcalc v. 11.3.0.0 (Medcalc, Mariakerke, Belgium)]. For all tests, $p < 0.05$ was considered to be indicative of a statistically significant difference.

The Mann–Whitney U test and the χ^2 test were used for quantitative and qualitative comparisons between benign and malignant SSTMs. Interobserver variability in the interpretation of the signal intensity pattern seen on DWI was assessed by using Cohen κ coefficients, and the interobserver reliability of ADC measurements was calculated using the intraclass correlation coefficient. A κ value of 0.00–0.20 indicated slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement.¹³ An intraclass correlation coefficient <0.40 indicated poor agreement; 0.40–0.75, fair to good agreement; and <0.75 , excellent agreement.^{14,15} The sensitivity, specificity and accuracy were also determined. In addition, a receiver-operating characteristic (ROC) curve analysis was performed in order to determine the optimal ADC cut-off value regarding the prediction of malignant SSTMs.

RESULTS

Demographic data and lesion size

With respect to the demographic data of the 60 patients (30 males and 30 females; mean age, 48.5 years; age range, 5–80 years), there was a significant difference in age between patients with benign and those with malignant SSTMs (mean age, 43.06 ± 19.16 years for benign and 56.16 ± 17.20 years for malignant SSTMs, $p = 0.009$). However, the sex ratio did not differ significantly between the two groups ($p = 0.432$). There was also no significant difference in the longest diameter of the lesions (mean size, 29.63 ± 21.26 mm; size range, 5–106 mm) between benign and malignant SSTMs (mean size, 28.43 ± 22.32 for benign and 31.32 ± 20.02 for malignant SSTMs, $p = 0.453$).

Qualitative analysis of diffusion-weighted images

The signal intensity characteristics of the SSTMs seen on DWI are shown in Table 3. By visual assessment, a large percentage of benign SSTMs showed a decreasing tendency towards signal intensity as the b -values increased [77.1% (27 of 35 lesions) for

Reader 1; 80% (28 of 35 lesions) for Reader 2; $df = 2$, $p < 0.001$ for both readers]. On the contrary, the majority of malignant SSTMs appeared to have an increasing tendency towards signal intensity as the b -values increased [72% (18 of 25 lesions) for Readers 1 and 2]. There were no grade 0 lesions among the malignant SSTMs for Reader 1. Weighted κ values showed substantial agreement ($\kappa = 0.81$) for analyzing the signal intensity pattern seen on DWI.

Quantitative analysis of apparent diffusion coefficients

Comparisons of ADCs of the SSTMs between benign and malignant lesions are summarized in Table 4. The mean ADC values obtained from the enhancing solid portions were lower than those from an entire mass, and both the group means ADC_{solid} and ADC_{entire} of malignant SSTMs were significantly lower than those of benign SSTM at three b -values (0, 400 and 800 s mm^{-2}) ($df = 58$, $t = 4.37$ for ADC_{solid} ; $df = 54.9$, $t = 4.42$ for ADC_{entire} ; $p < 0.001$). The thresholds of ADC values for discriminating between benign and malignant SSTMs and the areas under the ROC curves area are shown in Table 4. Although the diagnostic performance (area under the ROC curve) of both ADC values were nearly identical, the ADC cut-off value using ADC_{solid} revealed better diagnostic accuracy and clinical applicability while maintaining good sensitivity and specificity. ADC measurements showed excellent interobserver agreement (intraclass correlation coefficient = 0.82).

The benign SSTMs with low ADC_{solid} which resulted in false positives were epidermal inclusion cyst ($n = 3$), giant-cell tumour of tendon sheath ($n = 1$), angioleiomyoma ($n = 1$), haemangioma ($n = 1$), tumoral calcinosis ($n = 1$), fibromatosis ($n = 1$) and inflammatory myofibroblastic tumour ($n = 1$). In contrast, the malignant SSTMs with high ADC_{solid} resulting in false negatives included myxoid liposarcoma ($n = 1$) (Figure 2), undifferentiated pleomorphic sarcoma ($n = 2$), malignant peripheral nerve sheath tumour ($n = 1$) and melanoma ($n = 2$).

Diagnostic performance in the differentiation between benign and malignant superficial soft-tissue masses

The diagnostic performance (area under the ROC curve) with respect to differentiating SSTMs of both readers improved after additional review of the qualitative and quantitative DW images improved from 0.85 to 0.87 for Reader 1 and from 0.82 to 0.99 for Reader 2 (Table 5, Figure 3). Table 5 lists the sensitivity, specificity and accuracy of each reader in the diagnosis of malignant SSTMs using conventional MRI alone and in combination with qualitative and quantitative DWI. For Reader 2, with conventional MRI alone, the sensitivity, specificity and accuracy were 84%, 80% and 81.6%. With combined qualitative and quantitative DWI, the sensitivity, specificity and accuracy were 96%, 85.7% and 90%. Additional information from qualitative and quantitative evaluation of DW images improved the rate of correct diagnosis by 8.3% (5/60) (Figure 4). For Reader 1, additional information from qualitative and quantitative evaluation of DWI revealed the same accuracy of 86.7% without added value on correct

Table 3. Visual evaluation of the signal intensity pattern of superficial soft-tissue masses (SSTMs) seen on diffusion-weighted imaging at b -values of 0, 400 and 800 s mm^{-2}

Parameter	Grade 0	Grade 1	Grade 2
Benign SSTMs ($n = 35$)			
Reader 1	27 (77.1%)	5 (14.3%)	3 (8.6%)
Reader 2	28 (80%)	5 (14.3%)	2 (5.7%)
Malignant SSTMs ($n = 25$)			
Reader 1	0	7 (28%)	18 (72%)
Reader 2	1 (4%)	6 (24%)	18 (72%)

Grade 0, the signal intensity gradually decreased as the b -value increased; grade 1, little or no change in signal intensity was seen as the b -value increased; grade 2, signal intensity gradually increased as the b -value increased.

Table 4. The apparent diffusion coefficient (ADC) values and ADC cut-off values in benign and malignant superficial soft-tissue masses (SSTMs) using receiver-operating characteristic analysis

Parameter	Lesion type	Cut-off value	Sensitivity (%)	Specificity (%)	Accuracy (%)	AUC
ADC _{entire} ($\mu\text{m}^2 \text{s}^{-1}$)	Benign SSTMs	1496.7	100 (25/25)	51.5 (18/35)	71.7 (43/60)	0.794 [0.681, 0.907]
	1555.2 $\pm$ 606.1 ^a					
	Malignant SSTMs					
	1014.4 $\pm$ 333.2 ^a					
ADC _{solid} ($\mu\text{m}^2 \text{s}^{-1}$)	Benign SSTMs	1090.2	76 (19/25)	74.3 (26/35)	75 (45/60)	0.794 [0.682, 0.906]
	1386.8 $\pm$ 510.0 ^a					
	Malignant SSTMs					
	865.4 $\pm$ 363.5 ^a					

AUC, area under the receiver-operating characteristic curve; ADC_{entire}, mean apparent diffusion coefficient values obtained from an entire mass on one representative axial plane; ADC_{solid}, mean apparent diffusion coefficient values obtained from the enhancing solid portion. Numbers in parentheses are raw data. Numbers in brackets are 95% confidence intervals. Percentages were rounded.

^aValues are expressed as mean $\pm$ standard deviation.

diagnosis. However, there was improvement in the sensitivity by as much as 16%. Although the false-positive rate was increased by 6.7% (4/60), the false-negative rate was also reduced at the same rate for the experienced reader. The best diagnostic performance with respect to differentiation of SSTMs could be obtained when conventional MRI was assessed in combination with qualitative and quantitative DWI. The diagnostic performances (area under the ROC curve) evaluated by the ADC cut off values only (Table 4) were lower than that of the conventional MRI alone (Table 5).

DISCUSSION

Our study showed that the diagnostic performance for the evaluation of SSTMs had improved when both the conventional MR imaging and DW imaging were interpreted together for the readers with different durations of clinical experience in musculoskeletal imaging. For the less-experienced reader, added information regarding DW images led to the apparent improvement in the diagnostic accuracy, sensitivity and specificity. For the experienced reader, the addition of DWI increased the diagnostic sensitivity.

In clinical practice of tumour management, most clinicians usually determine the necessity for tissue confirmation of the tumour by considering the results of MRI interpretation. Similarly, during our study design, most of the 138 excluded patients who did not undergo follow-up biopsy had MRI results interpreted as benign category. It is more important for clinicians not to miss any of the malignant tumours; therefore, achieving high sensitivity for the imaging study is essential even if more false-positive cases occur. Thus, for an experienced reader, the improvement of diagnostic sensitivity by the addition of qualitative and quantitative evaluation of DWI to standard MR has a meaningful clinical impact in the differentiation of malignant SSTMs from benign ones, even if false-positive results can lead

to subsequent unnecessary invasive procedures such as tissue biopsy or mass excision.

The use of MRI for evaluating SSTMs is increasing for the characterization and differential diagnosis of lesions, although ultrasonography is the primary imaging modality used for evaluating the majority of superficial soft-tissue lesions. This is owing to the fact that ultrasonography findings are sometimes not sufficient to definitely characterize the nature of a lesion. For superficial masses, some factors have been reported that are indicative of malignancy on MR or ultrasonography imaging, such as fascial oedema, skin thickening, skin contact, internal haemorrhage or necrosis and lobulation of the mass.^{1,16,17} Unlike deep-seated masses, size criteria, *i.e.* 50 mm in diameter, is not an important factor in patients with superficial soft-tissue lesions. However, as these MR features do not always allow a correct diagnosis for differentiating malignant and non-malignant SSTMs, we attempted to evaluate the utility of adding DWI to conventional MRI in order to differentiate between them.

Unlike previously published reports,^{2,6,12,18} our study demonstrated that the mean ADC values for malignant and benign masses are significantly different. We assume that this discrepancy may be related to the difference in the tumour size and location, as most of the tumours in previous study populations were >5 cm in diameter and were deep-seated lesions. In our study, as most of the masses were <5 cm in diameter, there was a chance for more homogeneity and hypercellularity in the mass content. The ADC values would have been influenced by the myxoid tumours included in a previous report.^{2,4} However, even in that report, among non-myxoid tumours, the mean ADC value was significantly higher for benign tumours than for malignant tumours. Another previous study also supports our results because the mean ADC value of the desmoid tumours

Figure 2. A 44-year-old female with pathologically proven myxoid liposarcoma, which was not correctly identified after combined reading of diffusion-weighted imaging (DWI) (false negative). (a) Axial T_2 weighted (TR/TE, 2696/80) turbo spin-echo MR image of the right inguinal area showing an oval well-demarcated mass in the deep subcutaneous fat layer. Peritumoral or fascial oedema is hardly seen. (b) Axial fat-suppressed contrast-enhanced T_1 weighted image (TR/TE, 589/15) demonstrating a lesion with homogeneous enhancement. (c) Axial diffusion-weighted images (TR/TE, 5000/80) with b -values of 0 s mm^{-2} , 400 s mm^{-2} and 800 s mm^{-2} showing progressive loss of signal intensity within the mass (grade 0). (d) Axial apparent diffusion coefficient (ADC) map ($b = 0, 400$ and 800 s mm^{-2}) showing a high mean ADC value ($1470 \mu\text{m}^2 \text{ s}^{-1}$), which was interpreted as a benign lesion. The value was higher than the mean ADC value obtained from the enhancing solid portion of benign superficial soft-tissue masses ($1386.8 \pm 510.0 \mu\text{m}^2 \text{ s}^{-1}$). Histopathological findings revealing a myxoid liposarcoma with an abundant amount of myxoid stroma.

was significantly higher than that of malignant soft-tissue tumours.⁵ Therefore, quantitative DWI would be useful for differentiating between malignant and benign masses.

Of course, the myxoid component of the masses influenced the mean ADC values in our study. Two patients with malignant SSTMs with myxoid change were included, *i.e.* one patient with myxoid liposarcoma and one patient with malignant peripheral nerve sheath tumour. The mean

ADC_{solid} of malignant myxoid SSTMs ($1463 \pm 32.8 \mu\text{m}^2 \text{ s}^{-1}$) was higher than that of all benign SSTMs ($1386.8 \pm 510.0 \mu\text{m}^2 \text{ s}^{-1}$), which led to false-negative results. It has been reported that benign tumours can reveal low ADC values, such as epidermal inclusion cysts, angioleiomyomas, lipomas and localized or diffuse tenosynovial giant-cell tumours.^{2,4,19–21} These tumours contain little necrotic, cystic or myxoid areas and do not have a large extracellular space with a resulting decrease in their ADC values. We

Table 5. Diagnostic performance in the differentiation of benign and malignant superficial soft tissue masses

Parameter	Reader 1 (19 years' experience)		Reader 2 (2 years' experience)	
	Conventional MRI alone	Conventional and DWI	Conventional MRI alone	Conventional and DWI
AUC	0.85 [0.74, 0.96]	0.87 [0.78, 0.97]	0.82 [0.71, 0.93]	0.91 [0.83, 0.99]
Sensitivity (%)	76 (19/25)	92 (23/25)	84 (21/25)	96 (24/25)
Specificity (%)	94.3 (33/35)	82.9 (29/35)	80 (28/35)	85.7 (30/35)
Accuracy (%)	86.7 (52/60)	86.7 (52/60)	81.6 (49/60)	90 (54/60)
Added value in accuracy (%)	0 (0/60)		8.3 (5/60)	

AUC, area under the receiver-operating characteristic curve; DWI, diffusion-weighted imaging. Numbers in parentheses are raw data. Numbers in brackets are 95% confidence intervals. Percentages were rounded.

excluded patients with lipomas, in whom a definitive diagnosis is not difficult using only conventional MRI and focused on the differentiation of more confusing cases with equivocal findings.

As seen in other clinical studies,^{4,8,12,22–24} although most benign SSTMs showed a progressive signal loss and malignant SSTMs showed less signal loss with an increase in diffusion weighting, there were still a few equivocal cases with little or no signal change. DWI with a higher b -value, $>800 \text{ s mm}^{-2}$, would increase the contrast between benign and malignant lesions and thus reduce the number of equivocal cases.^{4,8,25} However, if the maximum high b -value is increased, the number of signal averages also has to increase to provide enough signal for visualizing the tumour by improving the signal-to-noise ratio.^{26,27}

Even though the ADC values of malignant SSTMs were significantly lower, there existed a considerable overlap between the benign and malignant groups. In our study, the ADC value could be affected by various factors, including different

acquisition parameters for each anatomical location and tumour physiology; therefore, the accurate threshold value between malignant and benign SSTMs is uncertain.^{24,28} As the ADC analysis showed the lowest diagnostic performance in the discrimination of malignant and benign SSTMs in our results, the ADC value alone should not be used for the differential diagnosis.

Our study has some limitations. First, the possibility of a selection bias, which could have resulted from the retrospective study design, should be considered. Second, the size of our study population was rather small. Third, the ratios of the ADCs of the SSTMs to the reference structure were not calculated. Since the molecular diffusion of water and the blood microcirculation of the capillary networks in each biological tissue could affect the ADC values,^{26,27,29} the variability in an individual's ADC value would be compensated by using the ADCs ratio.^{4,8} However, because of the spatial diversity of SSTMs from the neck to toe, it was almost impossible to determine a consistent reference structure in order to set the

Figure 3. Receiver-operating characteristic curves illustrating the comparison of the diagnostic performance of conventional MRI alone and conventional MRI with added information of diffusion-weighted imaging for the two readers in detecting malignant superficial soft-tissue masses.

Figure 4. A 60-year-old male with malignant melanoma. (a) Axial T_1 weighted (TR/TE, 450/16) turbo spin-echo MR image of the right calf showing a relatively small, *i.e.* 1.3 cm in the longest diameter, well-defined mass in the subcutaneous fat layer. (b) Axial fat-suppressed contrast-enhanced T_1 weighted image (TR/TE, 544/16) demonstrating a lesion with homogeneous enhancement. (c) Axial diffusion-weighted (DW) images (TR/TE, 5000/80) with b -values of 0 s mm⁻², 400 s mm⁻² and 800 s mm⁻² showing no significant decrease in the signal intensity within the mass (grade 1). (d) The corresponding axial apparent diffusion coefficient (ADC) map ($b = 0, 400$ and 800 s mm⁻²) showing marked low signal intensity (ADC, 545 $\mu\text{m}^2\text{s}^{-1}$). Using conventional MRI features, the mass was considered more likely to be benign. However, the high signal intensity on the DW image and low ADCs are highly suggestive of a malignant lesion. The histological findings confirmed the malignant nature of the mass.

ADC ratio. Fourth, the increased diagnostic accuracy observed for the combined image set may at least in part be attributable to the readers having gained experience in the interpreting steps. Fifth, the possibility of a recall bias should also be considered, although we attempted to avoid any recall bias by means of an interval review over a 3-month period and by changing the order in which the cases were reviewed. Sixth, we evaluated conventional MR and DW images side by side. However, to draw the ROI on the optimal lesion that best represents the character of the SSTM and to overcome the insufficient resolution of DWI, it must be examined

with conventional MRI. Seventh, inclusion of the b -value of 0 might have introduced perfusion-related diffusion effects into ADCs.⁴ Eighth, on DWI, we used “2” signal average which may not be enough for quantitative imaging. However, the number of signal average should be adjusted to practically reduce total scan time.

In conclusion, adding qualitative and quantitative DWI to conventional MRI can improve the diagnostic performance for differentiation between benign and malignant SSTMs.

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