Qualitative and quantitative performance of diffusion-weighted imaging in differentiation between benign and malignant soft tissue lesions

Doaa M. Fouad[a], Dalia O. Mohamed[b]

Departments of [a]Radiology, [b]Radiotherapy, South Egypt Cancer Institute, Asyut University, Asyut, Egypt

Correspondence to Doaa M. Fouad, MD, Department of Radiology, South Egypt Cancer Institute, Asyut University, Asyut, P.O. Box 71515, Egypt.
Fax: 0882348609.
e-mail: doaafouad11@gmai.com

Received 12 February 2020
Revised 17 February 2020
Accepted 19 February 2020
Published 11 June 2021

Journal of Current Medical Research and Practice
2021, 6:192–199

Introduction
MRI is the method of choice for the diagnostic workup of soft tissue lesions. Several studies have proved the ability of diffusion-weighted imaging (DWI) and apparent diffusion coefficients (ADC) to investigate the histological features of soft tissue tumors. However, its diagnostic potential is still questionable in avoiding unnecessary invasive maneuvers like biopsy or surgery owing to some overlapping characteristics between benign and malignant lesions.

Objective
The study aimed to evaluate the quantitative performance of the ADC and the qualitative performance of DWI in the differentiation between benign and malignant soft tissue lesions.

Patients and methods
A total of 50 patients with a histologically proof of newly diagnosed primary soft tissue tumors were retrospectively included in the study. All patients underwent MRI with DWI with sensitivities of *b* values (50, 400, 800, and 1000 s/mm^2). ADC values of the solid components of these tumors were obtained and were correlated with the histopathological results.

Results
The mean ADC value of the benign soft tissue lesions was 1.52×10^{-3} mm^2/s, with a range of 0.4–2.6×10^{-3} mm^2/s, and for the malignant soft tissue lesions was 0.78×10^{-3} mm^2/s, with a range of 0.5–2.02×10^{-3} mm^2/s. The cutoff of mean ADC was 0.86×10^{-3} mm^2/s, which showed the highest specificity (97.22%) and accuracy (94.55%).

Conclusion
Using quantitative ADC value to standard MRI can improve the diagnostic accuracy of differentiating malignant and benign soft tissue lesions. It is considered as an attractive noninvasive diagnostic tool, except for myxoid and lipid-rich neoplasms, which showed an overlap of ADC values.

Keywords:
apparent diffusion coefficient, benign, malignant, soft tissue neoplasms, diffusion-weighted imaging, MRI

J Curr Med Res Pract 6:192–199

2357-0121

Background

Differentiation between benign and malignant soft tissue tumors is still a common problem in imaging and clinical practice. Furthermore, it is very crucial to choose an appropriate management plan before the surgical approach [1,2]. The soft tissue tumors have characteristic internal components, consisting of interstitial tissues, such as collagen fibers, mucinous fluid, and myxoid materials, in addition to tumors cells, which affect their morphological and functional imaging [3,4]. Although MRI is widely used in evaluating and diagnosing soft tissue tumors, using the conventional imaging protocols does not fully identify malignancy in considerable proportion of patients [5,6]. This is because of some similarity of MRI appearances between benign and malignant soft tissue tumors in the size, margin, location, depth, signal intensities, and contrast-enhancement, which diminished its differentiation potential [6,7]. Functional and metabolic imaging techniques such as diffusion-weighted image (DWI) with apparent diffusion coefficient (ADC) analysis potentially improved the characterization of soft tissue tumor [5–7]. Visual analysis of DWI is very sensitive in the detection, but it is not useful for full determination of the malignancy differentiation [8–10]. Quantitative DWI with ADC analysis can be more helpful in this concern. The ADC values had been reported to be significantly higher in benign than in malignant soft tissue lesions [11]. However, many authors reported an overlap between ADC values of benign and malignant soft tissue lesions [8,12]. In addition, DWI and ADC are also helpful in predicting the tumor

subgroup regarding the myxoid, fat, or hemosiderin components [13,14].

The current study aimed to evaluate the quantitative performance of the ADC and the qualitative performance of DWI in the differentiation between benign and malignant soft tissue lesions.

Patients and methods

A total of 50 patients were retrospectively included in the study, in a period from October 2017 to October 2019. All patients were newly diagnosed with a primary soft tissue tumor with known histopathological type and underwent MRI study that included DWI and ADC map (with diffusion sensitivities of *b* values: 50, 400, 800, and 1000 s/mm) as inclusion criteria. The exclusion criteria were unavailable histopathological data, recurrent tumors, secondary tumors, and previous or concomitant exposure to chemotherapy or radiotherapy. Ethics approval and consent were considered and informed written consent was taken from all subjects.

MRI protocol

MR studies were conducted with a 1.5-T MRI (Philips-Achieva, Netherlands) and postprocessing analysis was done using Philips-Extended MR workstation. All cases were examined in supine position by using suitable body or surface coils which were used according to the site and extent of the lesion. Sequences were carried through out in axial, coronal, and sagittal planes, with slice thickness of 5–10 mm, interslice gap of 1–2 mm, field of view of 20–40 cm, and matri × 128 × 256. T1WI: (TR/TE = 500/14 ms; NEX = 1–2), T2 WI: (TR/TE = 2000–4000/30–90 ms NEX = 3), STIR: (TR/TE = 1420–1680/20–40 ms, inversion (TI)=150), and post contrast T1WI and T1 fat suppression with Gadolinium DPTA.

Diffusion-weighted MR imaging

DWI were obtained using a single-shot echo-planar imaging diffusion-weighted sequence (TR/TE/NEX: 2200/75 ms/2-3) with diffusion sensitivities of *b* values (50, 400, 800, and 1000 s/mm^2). Sections of 5 mm thickness, interslice gap of 1 mm, field of view 240–400 mm, and 128 × 256 matrix were used for all images. Scanning time was about 120 s. The number of slices varied from one patient to another, chosen in a manner that covered the entire tumor with an extraslice in each direction.

DWI and ADC map were generated followed by the application of a region of interest for each lesion. DWIs were assessed for qualitative assessment into restricted and facilitated. ADC map generated from DWI was used for quantitative assessment of lesions, which was done by application of region of interest in areas that showed high signal intensity of diffusion restriction on DWI (areas of calcification, cystic degeneration, hemorrhage, and blood vessels were avoided, guided by conventional sequences).

Statistical analysis

Statistical analysis was done in terms of mean, minimum, and maximum ADC using χ^2 test, the mean ADC values of malignant and benign lesions were calculated. Data were analyzed to test the statistical significance between ADC values. Differences in ADC values between malignant and benign soft tissue masses were evaluated using Student *t* test. *P* values less than 0.05 were considered as statistically significant at 95% confidence interval. The receiver operating characteristic curve was drawn to detect the cutoff point used to differentiate malignant from benign soft tissue masses, with calculation of sensitivity, specificity, accuracy, positive predictive value, negative predictive value, and area under the curve (AUC).

Results

The current study included 50 patients (23 males and 27 females) with soft tissue masses (33 benign and 17 malignant). Regarding the age distribution, eight (16%) patients were below 20 years, 18 (36%) were from 20 to 40 years, whereas the remaining 24 (48%) were above 40 years. No age or sex predominance was noted. Lower limbs were the most common location regarding both benign and malignant lesions, found in 30 (60%) patients, followed by the upper limbs by 13 (26%) patients and pelvic bone by six (12%), and lastly one (2%) patient was affected at the trunk.

The number of benign lesions, pathological types, and their ADC values (mean, minimum, maximum) are illustrated at Table 1, and malignant lesions are illustrated in the same manner in Table 2.

As for the benign soft tissue lesions, hemangioma was the most frequent pathological type, as it was represented by eight patients, followed by fibromatosis by five patients, then cavernous hemangioma by three patients. The study also included four cases of chronic organized abscesses and four cases of complicated cystic lesions (two ganglion cysts, lymphangia, and Baker's cyst) (Table 1). The mean ADC value of benign lesions ranged from 0.4 × 10^{-3} to 2.6 × 10^{-3} mm^2/s, where the highest mean ADC value was seen in Baker's

Table 1 Number, pathological types, and apparent diffusion coefficient values (mean, minimum, and maximum) of benign lesions

Soft tissue lesions	Number 33	Mean ADC value×10^{-3} mm^2/s	Minimum ADC value×10^{-3} mm^2/s	Maximum ADC value×10^{-3} mm^2/s
Hemangioma	8	2.34	1.7	2.49
Desmoids fibromatosis	5	1.42	1.25	1.61
Cavernous hemangioma	3	1.88	1.6	2.44
Neurofibroma	2	1.58	1.41	1.98
Schwannoma	1	1.47	1.39	1.88
Myxoid neurofibroma	1	2.2	1.9	2.3
Giant cell tumor of tendon sheath	2	0.9	0.82	1.1
Intraarticular angiofibrolipoma	1	1.5	1.2	1.9
Lipoma	1	0.4	0.3	0.7
Benign fibrous histiocytoma	1	1.6	1.22	2.1
Lymphangioma	1	2.2	2.1	2.41
Ganglion cyst	2	1.9	1.8	2.3
Complicated Baker's cyst	1	2.6	2.4	2.8
Chronic pyogenic abscess	4	1.2	1.08	1.89

ADC, apparent diffusion coefficient.

Table 2 Number, pathological types, and apparent diffusion coefficient values (mean, minimum, and maximum) of malignant lesions

Soft tissue lesions	Number 17	Mean ADC value×10^{-3} mm^2/s	Minimum ADC value×10^{-3} mm^2/s	Maximum ADC value×10^{-3} mm^2/s
Soft tissue sarcoma	5	0.71	0.66	0.82
Rhabdomyosarcoma	3	0.77	0. 70	0.88
Spindle cell tumor	3	0.71	0.66	0.80
Malignant peripheral nerve sheath tumor	2	0.8	0.75	0.87
Malignant fibrous histiocytoma	1	0.7	0.6	0.8
Myxofibrosarcoma	1	2.02	1.88	2.2
Malignant round cell tumor	1	0.86	0.7	0.95
Lymphoma	1	0.5	0.4	0.65

ADC, apparent diffusion coefficient.

cyst by 2.6×10^{-3} mm^2/s, and then hemangiomas by 2.34×10^{-3} mm^2/s, whereas the lowest ADC value was in lipoma by 0.4×10^{-3} mm^2/s.

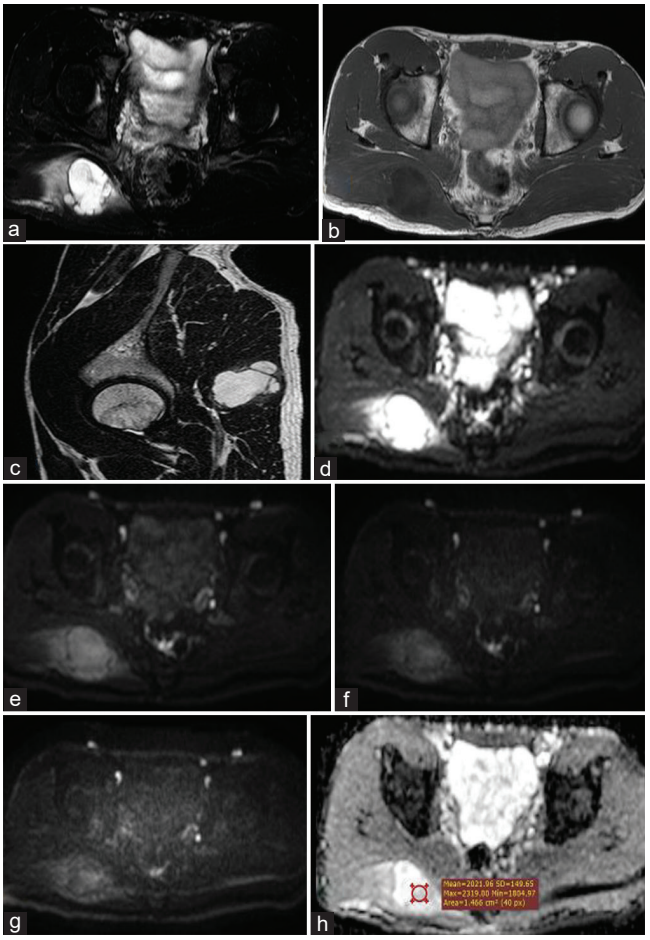
Regarding the malignant soft tissue masses, soft tissue sarcoma was the most common pathological type by five patients, followed by rhabdomyosarcoma and malignant spindle cell tumor by three patients for each (Table 2). For malignant soft tissue tumors, mean ADC values ranged between 0.5×10^{-3} and 2.02×10^{-3} mm^2/s. The lowest ADC value was seen in lymphoma by 0.5×10^{-3} mm^2/s, and the highest ADC value reached surprisingly 2.02×10^{-3} mm^2/s, which was seen in myxofibrosarcoma (Table 2).

The mean, minimum, and maximum ADC values for soft tissue lesions are illustrated in Table 3.

Regarding the average of the mean, minimum, and maximum ADC values of benign and malignant soft tissue lesions, there was a significant difference in the values as shown in Table 3, with significant *P* values (<0.001). The mean ADC value of benign soft tissue lesions was 1.52×10^{-3} mm^2/s, with a range from 0.4×10^{-3} to 2.6×10^{-3} mm^2/s. The mean ADC of malignant soft tissue lesions was 0.78×10^{-3} mm^2/s, with a range from 0.5×10^{-3} to 2.02×10^{-3} mm^2/s. Other benign lesions like benign myxoid neurofibroma (Fig. 1) showed relatively high mean ADC of 2.2×10^{-3} mm^2/s, whereas others showed ADC values close to the mean value such as intraarticular angiofibrolipoma (1.5×10^{-3} mm^2/s) (Fig. 2). In the same manner, some malignant tumors reveled values near the mean ADC like malignant peripheral nerve sheath tumor (Fig. 3) and malignant round cell tumors by 0.8×10^{-3} and 0.86×10^{-3} mm^2/s, respectively, whereas others like lymphoma showed much lower than the mean ADC by 0.5×10^{-3} mm^2/s.

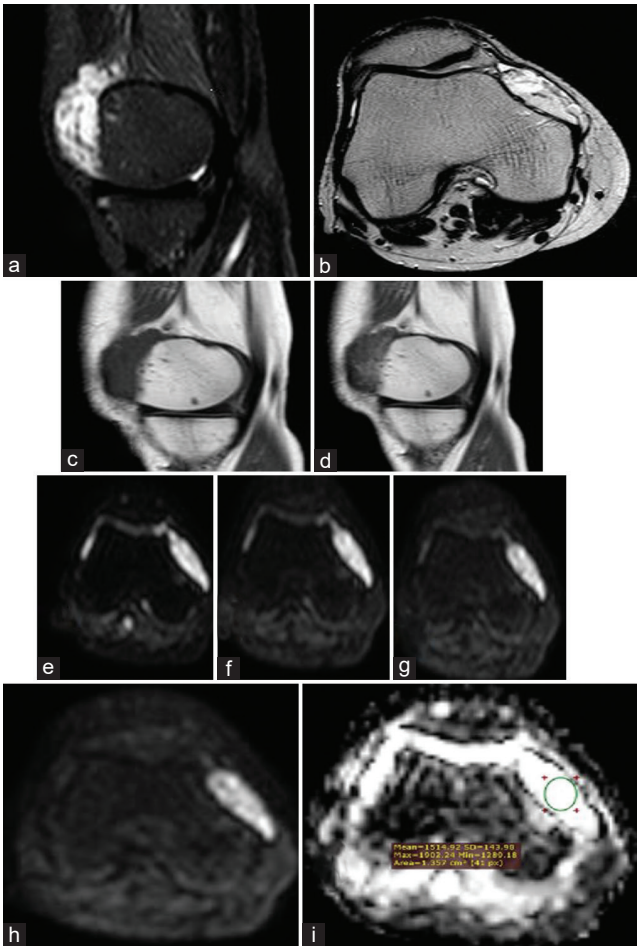
Qualitative analysis of diffusion images had been done with b values of 50, 400, 800, and 1000 s/mm^2 for all cases and reveled restriction of all malignant

Figure 1



(a) Axial STIR WI. It shows high SI lesion within right gluteal muscles with adjacent soft tissue edema. (b) Axial T1WI, low SI. (c) Sagittal T2 WI. High SI of near fluid signal, (d–g) DWI at *b* value of 50, 400, and 1000 s/mm^2 showing more or less facilitated diffusion on higher *b* values. (h) ADC map with ADC value calculated measuring ± 2.2 × 10^{-3} mm^2/s, with minimum ADC of 1.9 and maximum ADC of 2.3 × 10^{-3} mm^2. Biopsy was done by complete surgical excision biopsy and revealed benign myxoid neurofibroma. ADC, apparent diffusion coefficient; DWI, diffusion-weighted imaging.

Figure 2



(a) Sagittal STIR WI. Shows a medially located intraarticular high SI lesion with no adjacent bone marrow or soft tissue edema. (b) Axial T2 WI, high SI. (c) Sagittal T1WI, iso to low SI relative to muscles. (d) Sagittal T1WI postcontrast shows faint patchy enhancement. (e–g) DWI at b value of 50, 400, and 1000 s/mm^2 showing restricted diffusion. (h and i) ADC map showing T shine-through artifact with ADC value calculated measuring ± 1.5 × 10^{-3} mm^2/s, with minimum ADC 1.2 and maximum ADC 1.9 × 10^{-3} mm^2/s. Postoperative surgical excisional biopsy revealed intraarticular angiofibrolipoma. ADC, apparent diffusion coefficient; DWI, diffusion-weighted imaging.

Table 3 Mean, minimum, and maximum apparent diffusion coefficient values for soft tissue lesions

	Benign (*n*=36)	Malignant (*n*=19)	*P*
Mean ADC			
Mean	1.52×10^{-3} mm^2/s	0.78×10^{-3} mm^2/s	0.001
Range	0.4-2.6	0.5-2.02	
Minimum ADC			
Mean	1.2×10^{-3} mm^2/s	0.67×10^{-3} mm^2/s	0.001
Range	0.3-2.4	0.4-1.88	
Maximum ADC			
Mean	1.91×10^{-3} mm^2/s	0.93×10^{-3} mm^2/s	0.001
Range	0.7-2.8	0.65-2.2	

ADC, apparent diffusion coefficient.

soft tissue lesions, with significant *P* value (0.001). However, for benign lesions surprisingly, only 45.5% of them showed facilitated diffusion as in benign myxoid neurofibroma (Fig. 1e–g), whereas a large percentage of them (54.5%) showed restriction, such as intraarticular angiofibrolipoma (Fig. 2e–g), hemangiomas, chronic pyogenic abscesses, and desmoids fibromatosis. However, all of them showed mean ADC value above 1.2 × 10^{-3} mm^2/s, either restricted or facilitated.

Moreover, the cutoffs between benign and malignant lesions of each (mean, minimum, maximum) ADC were estimated and illustrated in Table 4.

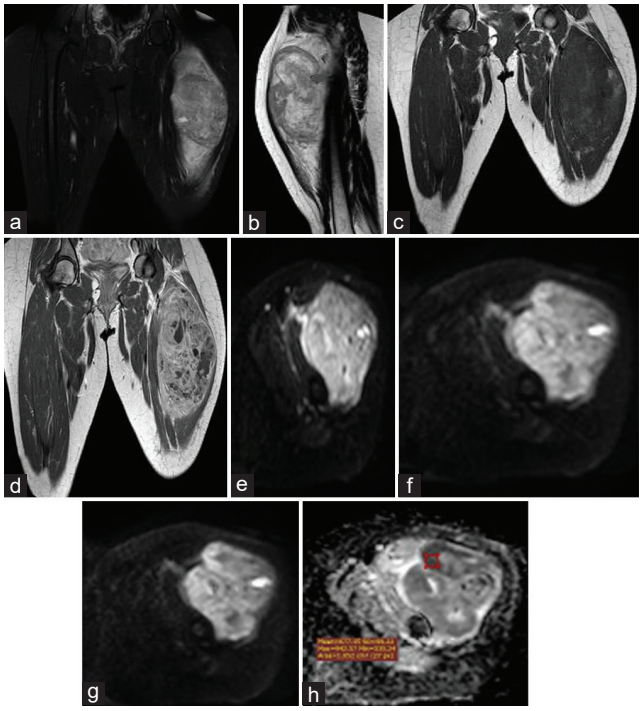
The cutoff of average mean ADC value was 0.86 × 10^{-3} mm^2/s, with sensitivity, specificity, positive predictive value, negative predictive value, accuracy, and AUC of 89.47, 97.22, 94.4, 94.6, 94.55, and 0.926%, respectively. However, the cutoff of average minimum ADC was 0.78 × 10^{-3} mm^2/s, with sensitivity, specificity, positive predictive value, negative predictive value, accuracy, and AUC of 89.47, 88.89, 81, 94.1, 89.09, and 0.895, respectively. Moreover, the cutoff of average maximum ADC value was 1 × 10^{-3} mm^2/s,

Table 4 Values for receiver operating characteristic curves for mean, minimum, and maximum cutoff between benign and malignant lesions

ADC value	Cutoff	Sensitivity	Specificity	PPV	NPV	Accuracy	AUC
Mean ADC	0.86×10^{-3} mm²/s	89.47	97.22	94.4	94.6	94.55	0.926
Minimum ADC	0.78×10^{-3} mm²/s	89.47	88.89	81.0	94.1	89.09	0.895
Maximum ADC	1×10^{-3} mm²/s	94.74	91.67	85.7	97.1	92.73	0.947

ADC, apparent diffusion coefficient; AUC, area under the curve; NPV, negative predictive value; PPV, positive predictive value.

Figure 3



(a) Coronal STIR WI shows a huge heterogeneous high SI lesion, involving anterolateral aspect of left thigh muscles with adjacent soft tissue edema. (b) Axial T2 WI: high SI lesion with areas of cystic degeneration. (c) Coronal T1WI: iso SI to adjacent muscles with bright foci suggesting hemorrhage. (d) Sagittal T1WI: postcontrast, showing heterogeneous enhancement. (e–h) DWI at b value of 50, 400, and 1000 s/mm² showing restricted diffusion. ADC map with ADC value calculated measuring mean: 0.8×10^{-3} mm²/s, with minimum ADC 0.75×10^{-3} mm²/s and maximum ADC 0.87×10^{-3} mm²/s. Histopathological study revealed malignant peripheral nerve sheath tumor. ADC, apparent diffusion coefficient; DWI, diffusion-weighted imaging.

with sensitivity of 94.74%, specificity 91.67%, positive predictive value 85.7%, negative predictive value 97.1%, accuracy 92.73%, and area AUC of 0.947.

The cutoff of mean ADC showed the highest specificity and accuracy, whereas the cutoff of maximum ADC showed highest sensitivity.

Discussion

The differentiation between benign and malignant soft tissue lesions is very important for appropriate management planning before surgical approach. MRI plays a fundamental role in the preoperative workup to evaluate tumor morphology, extent, and anatomical relationship with adjacent structures such as neurovascular bundles, joints, and bone marrow [12,15]. Previous studies demonstrated that conventional MRI was adequate regarding the tumors size, central necrosis, and signal heterogeneity. However, it is challenging alone in malignant or benign differentiation because of the overlap between them in imaging findings [7,15,16]. The quantitative assessment of water diffusion in tissues is expressed as ADC values; consequently, it provides a different tissue delineation more than that attained by conventional MR techniques. Although the values of DWI in assessing soft tissue tumors have been widely investigated, its role is still questionable for evaluation owing to the ADC value overlap between benign and malignant lesion, and its role to exclude the diagnostic invasive maneuver is still questionable [12–16].

The current study used the single-shot echo-planar imaging owing to rapid acquisition that reduces motion artifacts [17].

The current study demonstrated a significant difference in the mean, minimum, and maximum ADC values between benign and malignant, with significant *P* values (<0.001), and this was also reported by previous studies [13,18]. The mean ADC value of benign soft tissue lesions in current study was 1.52×10^{-3} mm²/s and for malignant was 0.78×10^{-3} mm²/s.

These results were in line with Pekcevik *et al.* [19] who reported 1.34×10^{-3} mm²/s as a mean of benign and 0.85×10^{-3} mm²/s of malignant. In the same order, Oka *et al.* [20] reported a mean ADC value of 1.55×10^{-3} mm²/s for benign lesions, which was significantly higher than of malignant (0.92×10^{-3} mm²/s) without any overlap. Some studies reported slightly higher mean ADC value for both benign and malignant of (1.71×10^{-3} and 1.0×10^{-3} mm²/s, respectively), but it still showed a statistically significant difference between them [12,21].

The significant difference between benign and malignant mean ADC attributes to the increased diffusion of water molecules in the extracellular spaces in benign lesions as compared with that of malignant soft tissue masses, which were expressed by higher ADC values [7] However, the slight variation of mean

ADC among studies might be owing to different pathological types of tumors in each study.

On the contrary, another study conducted on 29 lesions found no significant difference between these two groups, and this might be owing to their smaller sample size [22].

Regarding cases of soft tissue hemangioma, the average mean ADC value was 2.34×10^{-3} mm^2/s. This was convergent with Hassanien *et al.* [23] and other studies [24] who reported ADC value of 2.65×10^{-3} mm^2/s, whereas other studies reveled lower ADC values in hemangioma of 1.1×10^{-3} mm^2/s. This low ADC value in some hemangiomas might be owing to abundant fibrous tissue and thrombosis in its vascular spaces, which causes reduction of its ADC values [22].

As for cavernous hemangioma, the mean ADC value was 1.88×10^{-3} mm^2/s. This was somewhat near to the various studies, such as Robba *et al.* [8], who reported 1.68×10^{-3} mm^2/s, and more than Pekcevik *et al.* [19], who reported 1.3×10^{-3} mm^2/s, whereas it was lower than other study, which reported $2.2 \times x10^{-3}$ mm^2/s [23]. This close variation of the mean ADC among these studies may be owing to the variability in the amount of the thrombosed vessels among the cavernous hemangiomas [22].

The current study included four cases of organized chronic abscesses, which revealed high ADC values of 1.34×10^{-3} mm^2/s. This was near to Wu *et al.* [20,25] who reported 1.56×10^{-3} mm^2/s; this differentiated it from the soft tissue sarcoma in spite of the restricted DWI. These findings were also in line with previous studies, which stated that abscess has restricted diffusion with high ADC value, owing to high viscosity of its content caused by pus, inflammatory cells, and granulation tissue [26].

The desmoid fibromatosis in the current study revealed restricted diffusion but high mean ADC value of 1.35×10^{-3} mm^2/s, and minimum and maximum ADC values of 1.22×10^{-3} and 1.49×10^{-3} mm^2/s, respectively. These were close to the results of a recent study of Zeitoun *et al.* [27], in which the mean and minimum ADC values were 1.41×10^{-3} and 0.79×10^{-3} mm^2/s, respectively. Other studies reported that the mean ADC of fibromatosis ranged from 1.2 to 1.9×10^{-3} mm^2/s [5,27,28].

The predominance of high signal intensity on DWIs, whether purely or mixed, is indicative of fibromuscular tissue and mature fibrous tissue, which decreased water molecules' diffusibility and vice versa [29].

The lowest mean ADC value of benign lesions was found in lipoma by 0.3×10^{-3} mm^2/s; however, it was not conflictive because it has a classic appearance in conventional MRI. Many studies reported the same low ADC value, which was similar or lower than those of malignant soft tissue masses, with an average ADC value of 0.31×10^{-3} mm^2/s [23]. Einarsdóttir *et al.* [22] reported overlapping between benign and malignant lipomas, where restricted diffusion is present. This fact caused the difficult malignant differentiation and detection of malignant transformation of benign lipomas using ADC values.

Giant cell tumor of tendon sheath showed mean ADC value of 0.9×10^{-3} mm^2/s in spite of being benign. These results are compatible with those of Nagata *et al.* [12] who explained that Giant cell tumor of tendon sheath (GCTs). of the tendon sheath contain histiocytic mononuclear cells, multinucleated giant cells, xanthoma cells, and collagenous strands. These characteristics probably contribute to reducing the extracellular space and the concomitant decrease in ADC value [12].

The current study included two cases of myxoid tumors, one of them was benign myxoid neurofibroma, which showed facilitated diffusion with cyst like appearance and reported a mean ADC value of 2.2×10^{-3} mm^2/s, and the other one was high grade myxofibrosarcoma, which showed restricted diffusion with T2 shin through and ADC value of 2.02×10^{-3} mm^2/s. So there was no significant difference between benign and malignant myxoid lesions. Many previous studies revealed that myxoid-containing soft tissue tumors have significantly higher ADC values than the nonmyxoid because of the presence of myxoid matrix, high mucin, and low collagen content, resembling a high water content lesion [1,28]. Therefore, DWI and ADC were incapable in differentiating benign from malignant as both of them revealed high ADC value. Einarsdóttir *et al.* [22] used multishot echo-planar DWI sequence, and it was also not useful to differentiate between benign and malignant myxoid tumors.

Among the malignant lesions, the lowest mean ADC was detected in lymphoma by 0.45×10^{-3} mm^2/s, and these findings are compatible with Nagata *et al.* [30] who reported that lymphoma showed ADC values significantly lower even than sarcomas. As it is well known that lymphoma has a very high cellularity and elevated nuclear to cytoplasm ratio, so there is lower diffusivity of water molecules, thereby increasing DWI signal intensity of lymphomatous lesions [8,31,32].

The mean ADC value of malignant tumors in our study was 0.78×10^{-3} mm^2/s. This was in line with several studies such as Hassanien *et al.* [23] who reported

0.71×10^{-3} mm^2/s and near to those of Oka *et al.* [20] who reported of 1.02×10^{-3} mm^2/s.

The mean ADC cutoff value between benign and malignant tumors in current study was 0.86×10^{-3} mm^2/s. This result was convergent with Teixeira *et al.* [6] who reported 0.91×10^{-3} mm^2/s and lower than Hassanien *et al.* [23] who reported 1.2×10^{-3} mm^2/s; this variation may be owing to different ratios between numbers of benign and malignant tumors included in these studies.

The cutoff of mean ADC values between benign and malignant showed the highest specificity and accuracy whereas cutoff of maximum ADC showed highest sensitivity. Therefore, it is recommended to rely on the mean ADC value more than the minimum and maximum. Moreover, the qualitative performance of DWI, either facilitated or restricted, was not valid for benign lesions, whereas large percentage of them (54.5%) showed restriction. This is because of its distinctive internal components such as collagen fibers, mucinous fluid, or myxoid materials, so relying on qualitative performance of diffusion as indicator for malignancy in soft tissue tumors was not reliable.

The limitations of current study were the wide range of pathologies either neoplastic or inflammatory, the different age groups, and the susceptibility artifacts; the latter is considered as major limitation of any single-shot echo-planar imaging study, particularly at tissue interfaces, such as air or bone and soft tissue.

Conclusion

Quantitative DWI improves the diagnostic accuracy of standard MRI in distinguishing benign from malignant soft tissue tumors. It may reduce unneeded invasive maneuver. However, its role was limited in fat and myxoid rich tumors owing to significant overlapping between benign and malignant lesions.

Authors contributors

Doaa M. Fouad, performed the study design, wrote the manuscript, performed radiological assessment, the statistical analysis and is responsible for correspondence to journal. Dalia O. Mohamed, collected patient clinical, oncological data, and histopathological results.

Acknowledgments

The authors acknowledge everyone who helped and participated in the study, especially our patients.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Lee SY, Jee WH, Jung JY, Park MY, Kim SK, Jung CK, Chung YG. Differentiation of malignant from benign soft tissue tumour of additive qualitative and quantitative diffusion-weighted MR imaging to standard MR imaging at 3.0 T. Eur Radiol 2016; 26:743–754.

2 Costa FM, Ferreira EC, Vianna E. Diffusion-weighted magnetic resonance imaging for the evaluation of musculoskeletal tumors. Magn Reson Imaging Clin N Am 2011; 20:159–180.

3 Sagiyama K, Watanabe Y, Kamei R, Hong S, Kawanami S, Matsumoto Y, Honda H. Multiparametric voxel-based analyses of standardized uptake values and apparent diffusion coefficients of soft-tissue tumours with a positron emission tomography/magnetic resonance system: preliminary results. Eur Radiol 2017; 27:5024–5033.

4 Vickie YJo, Christopher D.M. Fletche. WHO classification of soft tissue tumours: an update based on the 2013 (4th) edition. Pathology 2014 (46): 95-104. Boston, USA.

5 Tran NA, Guenette JP, Jagannathan J. Soft tissue special issue: imaging of bone and soft tissue sarcomas in the head and neck. Head Neck Pathol 2020; 14:132–143.

6 Teixeira PAG, Gay F, Chen B, Zins M, Sirveaux F, Felblinger J, Blum A. Diffusion-weighted magnetic resonance imaging for the initial characterization of non-fatty soft tissue tumors: correlation between T2 signal intensity and ADC value. Radiol Med 2016; 122:871–879.

7 Fayad LM, Jacobs MA, Wang X, Carrino JA, Bluemke DA. Musculoskeletal tumors: how to use anatomic, functional, and metabolic MR techniques. Radiology 2012; 265:340–356.

8 Robba T, Chianca V, Albano D, Clementi V, Piana R, Linari A, *et al.* Diffusion-weighted imaging for the cellularity assessment and matrix characterization of soft tissue tumour. Radiol Med 2017; 122:871–879.

9 Mu Koh D, Collins DJ. Diffusion-weighted MRI in the body: applications and challenges in oncology. Am J Roentgenol 2007; 188:1622–1635.

10 Lecouvet FE. Whole-body MR imaging: musculoskeletal applications. Radiology 2016; 279:345–365.

11 Albano D, La Grutta L, Grassedonio E, Patti C, Lagalla R, Midiri M, *et al.* Pitfalls in whole body MRI with diffusion weighted imaging performed on patients with lymphoma. Magn Reson Imaging 2016; 34:922–931.

12 Nagata S, Nishimura H, Uchida M, Sakoda J, Tonan T, Hiraoka K, *et al.* Diffusion weighted imaging of soft tissue tumours: usefulness of the apparent diffusion coefficient for differential diagnosis. Radiat Med 2008; 26:287–295.

13 Razek A, Nada N, Ghaniem M, Elkhamary S. Assessment of soft tissue tumours of the extremities with diffusion echoplanarMR imaging. Radiol Med 2012; 117:96–101.

14 El Kady RM, Choudhary AK, Tappouni R. Accuracy of apparent diffusion coefficient value measurement on PACS. workstation: a comparative analysis. Am J Roentgenol 2011; 196:280–284.

15 Song Y, Yoon YC, Chong Y, Seo SW, Choi Y-L, Sohn I. Diagnostic performance of conventional MRI parameters and apparent diffusion coefficient values in differentiating between benign and malignant soft-tissue tumours. Clin Radiol 2017; 72:691.e1e691.e10.

16 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.

17 Hayashida Y, Hirai T, Yakushiji T, Katahira K, Shimomura O, Imuta M, *et al.* Evaluation of diffusion-weighted imaging for the differential diagnosis of poorly contrast-enhanced and T2-prolonged bone masses: Initial experience. J Magn Reson Imag 2006; 23:377–382.

18 Nagata S, Nishimura H, Uchida M, Hayabuchi N. Usefulness of diffusion-weighted MRI in differentiating benign from malignant musculoskeletal tumors. Nippon Acta Radiologica 2005; 65:30–36.

19 Pekcevik Y, Kahya MO, Kaya A. Characterization of soft tissue tumors by diffusion-weighted imaging. Iran J Radiol 2015; 12:e15478.

20 Oka K, Yakushiji T, Sato H, Yorimitsu S, Hayashida Y, Yamashita Y, *et al.* Ability of diffusion-weighted imaging for the differential diagnosis between chronic expanding hematomas and malignant soft tissue tumors. J Magn Reson Imag 2008; 28:1195–1200.

21 Van Rijswijk CS, Kunz P, Hogendoorn PC, Taminiau AH, Doornbos J,

Bloem JL. Diffusion-weighted MRI in the characterization of soft-tissue tumors. J Magn Reson Imag 2002; 15:302–307.

22 Einarsdóttir H, Karlsson M, Wejde J, Bauer HC. Diffusion-weighted MRI of soft tissue tumours. Eur Radiol 2004; 14:959–963.

23 Hassanien OA, Younes RL, Rasha M. Dawoud diffusion weighted MRI of soft tissue masses: can measurement of ADC value help in the differentiation between benign and malignant lesions? Egypt J Radiol Nuclear Med 2018; 49:681–688.

24 Mohammed YA. Role of diffusion MR imaging in musculoskeletal tumours. PhD thesis, Faculty of Medicine, South Valley Uni 2019.

25 Wu H, Zhang S, Liang C, Liu H, Liu Y, Mei Y, *et al*. Intravoxel incoherent motion MRI for the differentiation of benign, intermediate, malignant solid soft-tissue tumors. J Magn Reson Imaging 2017; 46:1611–1618.

26 Wong AM, Zimmerman RA, Simon EM, Pollock AN, Bilaniuk LT. Diffusion-weighted MR imaging of subdural empyemas in children. Am J Neuroradiol 2004; 25:1016–1021.

27 Zeitoun R, Khafagy SM, Mahmoud IH, El-Wahab NMA. Radiological evaluation of deep soft tissue fibromatosis, the characteristic MR criteria on conventional and corresponding diffusion-weighted images. Egypt J Radiol Nucl Med 2020; 51:8.

28 Maeda M, Matsumine A, Kato H, Kusuzaki K, Maier SE, Uchida A, Takeda K. Soft-tissue tumors evaluated by line-scan diffusion-weighted imaging: influence of myxoid matrix on the apparent diffusion coefficient. J Magn Reson Imaging 2007; 25:1199–1204.

29 Khoo MMY, Tyler PA, Saifuddin A, Padhani AR. Diffusion-weighted imaging (DWI) in musculoskeletal MRI: a critical review. Skelet Radiol 2011; 40:665–681.

30 Nagata S, Razek AA, Tirumani SH, Wienke A, Kahn T. Comparison of ADC values in different malignancies of the skeletal musculature: a multicentric analysis. Skelet Radiol 2015; 44:995–1000.

31 Albano D, Patti C, La Grutta L, Agnello F, Grassedonio E, Mulè A, *et al*. Comparison between whole-body MRI with diffusion-weighted imaging and PET/CT in staging newly diagnosed FDG-avid lymphomas. Eur J Radiol 2016; 85:313–318.

32 Galia M, Albano D, Narese D, Patti C, Chianca V, Di Pietto F, *et al*. Whole-body MRI in patients with lymphoma: collateral findings. Radiol Med 2016; 121:793–800.