Application potential of susceptibility-weighted imaging (SWI), diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI) in the diagnosis of soft tissue tumors.

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Abstract

Objective: The prime aim of the present study was to analyse the application value of 3.0 T Susceptibility Weighted Imaging (SWI), Diffusion Weighted Imaging (DWI) and Diffusion Tensor Imaging (DTI) sequence in the diagnosis of benign as well as malignant soft tissue tumors.

Methods: 30 cases of benign soft tissue tumor and 30 cases of malignant soft tissue tumor (diagnosed pathologically) were selected as study subjects. Routine MRI scanning sequences *viz.* SWI, DWI and DTI sequences were utilized for the examination.

Results: The DWI Apparent Diffusion Coefficient (ADC values) under different b values (400 s/mm^2, 800 s/mm^2) in malignant group were significantly less in comparison to benign group (P<0.05). Further, ADC values of cystic change and necrotic zone in malignant group were also significantly less than the benign group (P<0.05). On the other hand, the occurrence rate of hemorrhage, calcification, cystic change, necrosis, and fiber separation determined by SWI in malignant group was significantly higher when compared with benign group (P<0.05). The mean FA value and RA values of malignant tumor determined by DTI sequence examination were significantly higher than those of benign tumor. Also, VR values of malignant tumors were lower than that of benign tumors (P<0.05). The anisotropy of benign tumor parenchyma was lower than that of malignant tumor. Three-dimensional fiber tracking imaging showed that there was a difference in the influence of benign tumor and malignant tumor on adjacent muscle fiber bundle.

Conclusion: SWI, DWI and DTI sequence could be utilized for the identification of the benign/malignant soft tissue tumor, tumor anatomical boundary as well as respectability of malignant tumors.

Keywords: Susceptibility weighted imaging, Diffusion weighted imaging, Diffusion tensor imaging, Soft tissue tumor.

Introduction

Soft tissue tumors are characterized by the complicated structures and unique manifestations. So, the anatomical as well as clinical differential diagnosis of soft tissue benign and malignant tumors is quite challenging [1]. Magnetic Resonance Imaging (MRI) has a high resolution for tissue density, and it allows multi-directional 3D reconstruction of lesions. This 3D reconstruction helps in detailed exploration of the position, shape, size, boundary of lesion and its relationship with adjacent tissues. Moreover, magnetic resonance signal could also reflect partial histological features of lesion. Hence, MRI is used as a first choice for the examination of soft tissue tumors [2]. However, mere information on morphological characteristics by MRI could not reveal the complete understanding of the lesion. Moreover, the coincidence rate of the above qualitative diagnosis with pathological results was just 20-30% [3]. Functional Magnetic Resonance Imaging

(fMRI) mainly focuses on observing the microscopic movement of water molecules, which is widely used in the diagnosis of central nervous system disease [4]. Diffusion Weighted Imaging (DWI) is used to observe the proton energy movements. It also helps to detect the changes during developmental process of diseases in terms of cell density, integrity, geometric shape of extracellular space and tissue perfusion [5]. Echo Planar Imaging Diffusion Weighted Imaging (EPI-DWI) is characterized by the good image quality along with short scan time making it the most common scanning technique [6]. Further, Susceptibility Weighted Imaging (SWI) sequence in nervous system has proved its ability to display the tiny hemorrhagic lesion, vein vessels, blood supply and hemorrhage in tumor, etc. [7]. However, there is a paucity of information with regard to its application in soft tissue except soft tissue hematoma and cavernous hemangioma [8]. Diffusion Tensor Imaging (DTI), based on

DWI, exerts diffusion sensitive gradient field to conduct the 3D quantitative detection of anisotropy of water molecules in multiple directions within the tissue. This in turn helps in noninvasive and continuous display of the whole fibrous structure and its spatial distribution and such a technique is known as the Fiber Tracer Technique (FT) [9]. DTI and FT have been maturely applied in the nervous system [10]. The present study is the first of its kind to study the application potential of SWI, DWI and DTI for detection of soft tissue tumor.

Materials and Methods

Study design

Study comprised of 2 groups with 30 cases in each group. First group had patients with pathologically confirmed benign soft tissue tumors. Second group had patients with pathologically confirmed malignant soft tissue tumors. The above subjects were admitted to our hospital between January 2015 and January 2016.

Inclusion criteria: 1. Cases whose lesion could be measured and analysed with good image quality. 2. Cases without contraindications to MRI examination.

Exclusion criteria: Cases whom had a history of surgery, radiotherapy, chemotherapy and trauma at examination site. In category of benign tumors there were 16 males and 14 females with average age of 46.8 ± 13.3 y. Furthermore, benign tumors included 12 cases of hemangioma, 6 cases of soft tissue abscess and 12 cases of neurogenic tumor. In malignant tumor cases, there were 18 males and 12 females with average age 49.2 ± 15.6 y. These malignant tumors in turn included 10 cases of metastatic tumor, 5 cases of non-Hodgkin's lymphoma, 9 cases of liposarcoma, 3 cases of multiple myeloma, 1 case of chordoma and 2 cases of gastrointestinal mesenchymal tumors.

Research methods

The same MRI technician and nursing team conducted the examination to address subjective bias. 3.0 T MRI Scanner with 8-channel phased array coil (Siemens SKYRA 3.0 T) was used. Firstly, the routine MRI examinations followed by multiplanar scanning were conducted, including the TSE-T1WI, TSE-T2WI and T2WI-SPAIR. The scanning parameters for different sequences used are given below.

The scanning parameters of TSE-T1WI: TR=500 ms, TE=10 ms, layer thickness=5 mm, interval=1.5 mm, FOV=250 mm × 250 mm, matrix=300 × 240, NSA=2; those of TSE-T2WI were as follows: TR=4000 ms, TE=100 ms, layer thickness=5 mm, interval=1.5 mm, FOV=250 mm × 250 mm, matrix=300 × 240, NSA=2.

Parameters for T2WI-SPAIR: TR=4000 ms, TE=85 ms, layer thickness=5 mm, interval=1.5 mm, FOV=250 mm × 250 mm, matrix=260 × 200, NSA=2. Then, DWI and SWI scanning was conducted; SE-EPI and SENSE technique were used in DWI, and the scanning parameters were as follows: TR=1200 ms, TE=45 ms under b value=400 s/mm^2 or TE=53 ms under b value=800 s/mm^2, layer thickness=5 mm, interval=1.5 mm, isotropy, scanning number of layer=12, FOV=300 mm × 300 mm, matrix=128 × 128, NSA=4, scanning time=50 s. Parameters of SWI: TR=14 ms, TE=20 ms, NSA=1, FOV=220 mm × 180 mm, scanning number of layer=300, scanning time=about 10 min. In DTI, optimized DTI sequence parameter was selected, cross-section MDDW-EPI was used and diffusion gradient was exerted in 20 directions (b value=600 s/mm^2, FOV=350 mm × 350 mm, TR=8500 ms, TE=85 ms, number of layer=50, layer thickness=3 mm, no interlayer spacing, pre- and post-phase encoding direction, 3-order mean, bandwidth=1500 Hz/px, SNR=1.0, voxel size=2.7 mm × 2.7 mm × 3.0 mm); iPAT, accelerated factor 2 and GRAPPA algorithm was used to reduce the image artifact.

Image acquisition and processing: SWI was automatically generated by the built-in SWI software in MRI scanner so as to evaluate the focal hemorrhage, necrosis, calcification, cystic change, venule and fiber separation. Two senior MRI technicians interpreted SWI independently, and the third MRI diagnostician was needed in disagreements, to reach a consensus. DWI generated its corresponding ADC image in Siemens workstation combined with routine MRI. ADC values were measured in the layer with largest lesion area, uniform parenchymal composition, cystic change and necrotic zone. 3 ROIs were selected in each measurement, keeping focal parenchymal component as far as possible, and the ROI area ranged from 35 to 65 mm^2. Three groups of data were measured and averaged. DTI data were loaded into the NEURO 3D software that automatically generated the Fractional Anisotropy (FA) color-coded image, Relative Anisotropy (RA) map, Volume Ratio (VR) map and eigenvalue (λ_1) map. ROI was placed in the center of optimal layer of corresponding soft tissue visualization, and each ROI included five voxels. There were 3-5 ROIs in each area, and their average was taken as the measured value of the respective region. Under the fusion mode, we combined routine MRI scanning, b_0 and ADC image. The diffusion points were placed in the corresponding maximum cross section of each soft tissue; the control parameters used were FA threshold=0.13, step length=1.0 mm and angle threshold=20º.

Observation index

The diagnostic accuracy of benign as well as malignant tumors were explored in terms of tumor diameter, tumor area, surgical resection rate, ADC value, SWI characteristics and DTI characteristics, (including the FA value, RA value and VR value). The observations were made in the tumor parenchymal boundary, and anisotropy λ_1 value on the adjacent muscle fiber bundle.

Statistical methods

SPSS20.0 software was used for statistical analysis. The measurement data are presented as mean ± standard deviation.

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The independent sample t-test was used in the intergroup comparison; the enumeration data were presented as the number of cases (%), and χ^2 test was used in the intergroup comparison. P<0.05 signified statistical significant difference.

Results

Comparison of diagnostic accuracy, tumor diameter, tumor area, and surgical resection rate of benign/malignant tumors

There were no significant differences in the comparisons of diagnostic accuracy, tumor diameters, tumor areas, and surgical resection rates of benign and malignant tumors (P>0.05, Table 1).

Comparison of ADC values

ADC values in malignant group were significantly lower than that of benign group (P<0.05) as observed under different b values (400 s/mm^2, 800 s/mm^2), ADC values of cystic change and necrotic zone in malignant group were also significantly less in comparison to benign group (P<0.05, Table 2).

Comparison of SWI characteristics

The occurrence rates of hemorrhage, calcification, cystic change, necrosis, venules and fiber separation in malignant group were significantly higher than that in benign group as determined by SWI (P<0.05, Table 3).

Comparison of DTI characteristics

The mean FA and RA values of malignant tumor were significantly higher than those of benign tumor. On the other hand, the VR value of malignant tumor was lower than that of benign tumor, and the differences were statistically significant (P<0.05). The anisotropy of benign tumor parenchyma was lower than that of malignant tumor, but λ_1 value had no statistical significance (P>0.05) (Table 4). According to the three-dimensional fiber tracking imaging, the influence of benign tumor on adjacent muscle fiber bundle was mainly characterized by edema and translocation. However, the malignant tumor was characterized by significant decline in anisotropy, infiltration change along with damage of progression direction.

Table 1. *Comparison of diagnostic accuracy, tumor diameter, tumor area, and surgical resection rate of benign/malignant tumors.*

Group	Diagnostic accuracy (cases (%))	Tumor diameter (cm)	Area (cm^2)	Surgical resection rate (cases (%))
Benign tumor (n=30)	25 (83.33)	3.4 ± 0.8	12.5 ± 4.6	28 (93.33)
Malignant tumor (n=30)	24 (80.00)	3.7 ± 0.9	16.7 ± 5.8	26 (86.67)
t/χ^2	0.111	0.365	0.524	0.185
P	0.739	0.659	0.412	0.667

Table 2. *Comparison of ADC value (× 10^{-3} mm^2/s).*

Group	b value		b value of cystic change and necrotic zone	
	400 s/mm^2	800 s/mm^2	400 s/mm^2	800 s/mm^2
Benign tumor (n=30)	1.82 ± 0.44	1.56 ± 0.36	3.15 ± 0.33	3.06 ± 0.31
Malignant tumor (n=30)	1.59 ± 0.35	1.12 ± 0.32	2.89 ± 0.26	2.59 ± 0.25
t	4.658	4.123	5.126	5.541
P	0.02	0.025	0.012	0.009

Table 3. *Comparison of SWI characteristics (cases (%)).*

Group	Hemorrhage	Calcification	Cystic change and necrosis	Venules	Fiber separation
Benign tumor (n=30)	5 (16.67)	3 (10.00)	6 (20.00)	2 (6.67)	5 (16.67)
Malignant tumor (n=30)	20 (66.67)	13 (43.33)	22 (73.33)	10 (33.33)	15 (50.00)
χ^2	15.429	8.523	17.143	6.667	7.5
P	0	0.004	0	0.01	0.006

Table 4. *Comparison of DTI characteristics.*

Group	FA value	RA value	VR value	λ_1 value
Benign tumor (n=30)	0.13 ± 0.06	0.12 ± 0.05	0.97 ± 0.09	1.68 ± 0.06
Malignant tumor (n=30)	0.26 ± 0.08	0.23 ± 0.08	0.91 ± 0.08	1.59 ± 0.05
t	7.625	5.649	4.328	0.352

P	0.002	0.013	0.029	0.763

Discussions

DWI sequence in MRI has higher resolution as limiting the free motion of water molecules decreases the signal attenuation. The movement condition of water molecules is usually presented as ADC value. To get a high-quality dispersion image, it is needed to add additional sensitive gradient (SENSE technique) to SE-EPI, to quantify the dispersion degree of water molecules. Diffusion sensitive gradient needs two gradient fields on both sides of 180º pulse. The signal attenuation degree of water molecules is proportional to the free motion and gradient field density. When b value is 0, the signal is high in image; as b value increases, the signal of each tissue in human body is attenuated and lowered gradually. We observed statistically significant decrease in ADC values of malignant tumors in soft tissues. The cell proliferation of malignant tumor has been reported to be vigorous as compared to that of benign tumor [11]. Furthermore, the malignant tumor cells are characterized by the large density and atypical cell structure, thereby significantly limiting the free motion of water molecules and greatly decreasing the ADC value. Sugahara et al. [12] found that the higher the density of malignant cerebral tumor cell is, the less its extracellular space and composition leading to the lower the ADC value. Ducatman et al. [13] also pointed out that the density of breast tumor cell is negatively correlated with the corresponding ADC value. In the cystic change and necrosis of malignant lesions there is formation of viscous liquid by necrotic tissue, inflammatory cells and bacteria, so the water molecular diffusion is significantly limited, leading to lower ADC value along with the increase of b value. The benign lesions mostly have the serous fluid and mucus, so the tissue element is relatively simpler and the viscosity is also relatively lower than that of malignant lesions, thus having little limitation on the free motion of water molecules; thus, the ADC value is not decreased significantly with the increase of b value [14]. Similar observations were also noticed in the present study in the malignant tumors of soft tissues.

SWI is highly sensitive to the examination of hemoglobin metabolites (e.g., hemosiderin, ferritin), iron deposition, hemorrhage and calcification in the lesion. SWI has both high sensitivity and specificity in vascular imaging. The vascular tissue plays an important role during carcinogenesis and inflammation [15]. The qualitative diagnosis of tumor could initiate from the vascular proliferation and micro hemorrhage to clearly displayed tumor boundary, internal structure and tumor hemorrhage [16]. We noticed significant increases in the incidence rates of hemorrhage, calcification, cystic change, necrosis, venules and fiber separation in malignant group as observed by SWI sequence. Reichenbach et al. [17] reported that the resolution ratio could be increased from 1 mm^3 in the conventional case to 0.25 mm^3 in 3.0 T magnetic field, which displays the small vein structure more clearly, and its echo time could be shortened from 40-50 ms to 17-28 ms leading to shorter scan time. In addition, SWI could also effectively distinguish between calcification and luminal structure, and the calcium phase of the hemorrhage or vein [18]. Generally, the dark spots in tumor are considered as calcification, and the light signals are veins.

DTI reflects the anisotropy index of water molecule diffusion direction in the human tissue unit voxel, calculated on the basis of eigenvector value. According to the anatomical position, the main eigenvector of unit voxel fiber bundle in body tissue along the left-right direction is encoded with red color. Further, the front-back direction is encoded with green color and the head-tail direction is encoded with blue color. The FA value of tumor parenchyma has been reported earlier to be significantly decreased in comparison to that of normal muscle tissue [19]. Similar observation was noticed in our study results where, significant decrease was revealed in the FA values in malignant tumors of soft tissues. Further, VR values results are always on opposite end as the calculation method of VR is different from that of FA and RA.

Conclusion

The present study concludes that the high-field MRI for soft tissue tumor, using the SWI, DWI and DTI sequences is a reliable basis for the clinical scientific assessment of soft tissue tumor.

Conflict of Interest

None

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