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T2-star (T2*)-weighted magnetic resonance imaging of tenosynovial giant cell tumors

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HIGHLIGHTS

- The characteristics of the MRI signal intensities in cases with tenosynovial giant cell tumors (TSGCTs) were analyzed.
- T2*-weighted imaging was useful to distinguish lesion from muscle, particularly in large joints.
- T2*-weighted MR images are useful in a tissue-specific manner for the assessment of the tumor extension.

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ABSTRACT

Purpose: Tenosynovial giant cell tumors (TSGCTs) are benign but aggressive lesions, and the treatment is resection. A low to intermediate signal intensity on both T1- and T2-weighted images of magnetic resonance imaging (MRI) is characteristic, which is similar to the signal intensity of muscle, and therefore can be challenging for lesion detection. T2-star (T2*)-weighted MR images reflect paramagnetic deoxyhemoglobin, methemoglobin, or hemosiderin.

Methods: In 23 TSGCT patients (6 male and 17 females), the T2*MRI findings were analyzed. The tumor locations involved 10 large joints including nine knees and one ankle, 10 small joints including six fingers and four toes, as well as three wrists/hands.

Results: Ten diffuse and 13 localized tumors were predominantly located in the large joints and small joints, respectively. The T2*-weighted images indicated three signal patterns of low, iso and high signal intensity compared to muscle. Low-, iso- and high-signal intensities were seen in 22 (96 %), 23 (100 %) and 12 (52 %) of the locations, respectively. To distinguish TSGCTs from the surrounding tissue, the low intensity T2*-weighted images and low to intermediate intensity T1-weighted images when compared to muscle and fluid, respectively were useful for the large joints. Low to intermediate intensity on T1- or T2-weighted images was useful to distinguish TSGCTs from subcutaneous tissue in the small joints.

Conclusions: MRI using T2*-, as well as T1- and T2-weighted images, may be useful to detect lesions and assess the extent of TSGCTs in a tissue-specific manner, which is important for surgical planning.

1. Introduction

Tenosynovial giant cell tumors (TSGCTs) are characterized by proliferating mononuclear histiocytic cells in a sheet-like pattern with a fibrosclerotic stroma, accompanied by multinucleated giant cells and hemosiderin deposition. TSGCTs can be intra-joint, extra-joint, or both. TSGCTs are classified as "localized" or "diffuse", according to the growth pattern [1]. Localized TSGCTs are often referred to as giant cell tumors of the tendon sheath, and predominantly occur adjacent to small joints. Diffuse TSGCTs are often referred to as pigmented villonodular synovitis, and predominantly affect large joints such as the knees. Diffuse TSGCTs tend to recur and be locally aggressive [2,3]. A high recurrence rate after diffuse TSGCT resection has been reported [4], and complete resection can reduce the recurrence rate [5].

Magnetic resonance imaging (MRI) can be used to characterize and estimate the morphological characteristics, such as cystic changes, as well as the extent of soft tissue tumors. This imaging technique is currently the method of choice for the diagnosis of TSGCT. TSGCTs are

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reported to have low to intermediate signal intensity on both T1- and T2-weighted MR images. This rather low signal intensity is thought to be due to the presence of hemosiderin deposition [6–8]. The characteristic low to intermediate signal intensity of TSGCTs is similar to that of the muscle, therefore, detection of TSGCTs in muscle is difficult, particularly for the differentiation of lesions in muscles.

T2*(star)-weighted images are used to depict paramagnetic deoxyhemoglobin, methemoglobin or hemosiderin in lesions and tissues, with low signal intensity [9]. In clinical applications, a T2*-weighted image can be used to depict hemorrhage associated with vascular lesions, such as vascular malformations, phleboliths in vascular lesions, and hemosiderin deposition in joints in conditions such as hemophilic arthropathy [9,10]. TSGCTs, particularly diffuse types, are also candidates for T2*-weighted imaging [9], though there is less documentation for this application, as well as with localized TSGCTs.

T2*-weighted images can be used not only for making the image diagnosis, but also for the detection of lesions and the lesion extension. In the current study, the characteristics of TSGCTs were analyzed on T2*-weighted images. In addition, a possible characteristic finding of cystic changes on T2-weighted images was examined.

2. Materials and methods

2.1. Patients

All patients were referred to our institute. Only patients who underwent TSGCT resection were included, and the pathological diagnosis was confirmed with the resected tissue. The TSGCT cases with T1-, T2- and T2*-weighted imaging of any section were included in the study. Classification of localized or diffuse type was performed. Localized TSGCTs were characterized by solitary or few nodular lesions. Diffuse TSGCTs were characterized by lesions with multiple synovial-like structures or pathological villous structures. TSGCTs have been reported to have low to intermediate signal intensity on both T1- and T2-weighted MR images [6–8]. In this study, additional findings of cystic changes on T2 weighted images were investigated. On the T2*-weighted images, the characteristic MR signal intensity was assessed in comparison to the surrounding normal tissue. In a groupwise comparison, the knee and the ankle were classified as large joints, while the finger and toes were considered small joints. Lesions in the wrist and hand were not classified as either small or large joints.

2.2. Statistical analysis

Data were analyzed by Mann-Whitney U test for quantitative data and the chi-squared test for qualitative data. A p value of less than 0.05 was considered statistically significant.

3. Results

3.1. Demographic data

A demographic summary is shown in Table 1. The 23 patients consisted of six males and 17 females, with a mean age of 44.7 years old, ranging from 11 to 74. Tumor locations included nine cases in the knee, six cases in the finger, four cases in the toe, three cases in the wrist/hand, and one case in the ankle. Ten cases were classified as diffuse (43 %) and 13 cases were classified as localized (57 %). The large joints of the knee and the ankle cases were classified as diffuse in 8 out of 9 in the knee and one in the ankle (1/1). All cases in the small joints were classified as localized in the 6 fingers and the 4 toes. The 3 wrist/hand cases consisted of one diffuse and two localized types. There was an association between diffuse classification and large joints ($p < 0.01$). Fig. 1 shows the representative histology of the diffuse TSGCTs.

Table 1
Clinical summary of tenosynovial giant cell tumors on MRI.

Site	n	Age	M/F	Diffuse Localized	T2*-WI		T2-WI
					Low-signal area	High-signal area	Cystic change
Knee	9	48.3	1/8	8/1	9 (100 %)	6 (70 %)	4 (44 %)
Ankle	1	39	1/0	1/0	1(100 %)	1(100 %)	1(100 %)
Wrist/Hand	3	45.0	0/3	1/2	2 (67 %)	0 (0 %)	0 (0 %)
Finger	6	46.3	2/4	0/6	6 (100 %)	3 (50 %)	0 (0 %)
Toe	4	35.5	2/2	0/4	4 (100 %)	2 (50 %)	0 (0 %)
Total	23	44.7	6/17	10/13	**22 (96 %)**	12 (52 %)	5 (22 %)

F, female; M, male, WI; weighted image, T2*: T2 star, MRI; magnetic resonance imaging.

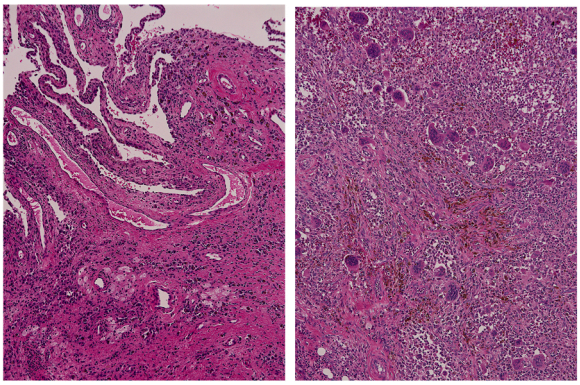

Fig. 1. Representative histology of a diffuse TSGCT. The lesion has a villous structure (left). The lesion is composed of proliferating spindle-shaped cells with fibrosclerotic stroma. Osteoclast-like giant cells are scattered throughout. Hemosiderin laden histiocytes can also be observed (right).

3.2. MRI signals in tenosynovial giant cell tumors

A summary of the MRI findings for the TSGCTs is shown in Table 1. On the T2*-weighted images, an area with iso signal intensity compared to muscle was seen in all TSGCT cases. Low signal intensity on T2*-weighted imaging was seen in 22 out of 23 cases (96 %). One case without low signal intensity on T2*-weighted image was a wrist/hand case. A high signal intensity region was seen in 12 out of 23 cases (52 %). The distribution of low or high signal intensities on T2*-weighted images varied depending on the case. There was no site-specific difference in the T2*-weighted images. Cystic changes were demonstrated on T2-weighted imaging, since joint fluid has a high signal intensity, while the TSGCTs have low to intermediate signal intensity. Overall cystic changes were seen in five of 23 cases (22 %). Cystic changes were seen in only half of the large joints (5/10: 50 %), including 4/9 of the knees (44 %) and one in the ankle (1/1: 100 %). No cystic changes were seen in the small joints (0/10: 0 %) of fingers and toes, and wrist/hand (0/3: 0 %). Cystic changes were characteristic of diffuse TSGCTs in the large joints ($p < 0.01$).

3.3. MRI signals in tenosynovial giant cell tumors and the normal tissue

The signal intensities on T1-, T2- and T2*-weighted imaging of TSGCTs compared to the surrounding normal tissue were assessed (Table 2). Muscle has low signal intensity on T1- and T2-weighted images. Subcutaneous fat has high signal intensity on T1- and T2-weighted images. Joint fluid has low signal intensity on T1-weighted and high

Table 2
MRI signals in normal tissue and tenosynovial giant cell tumor.

Tissue	T1-WI	T2-WI	T2*-WI
Muscle	low	low	iso
Fat	high	high	iso
Fluid	low	high	high
TSGCT	low to intermediate	low to intermediate	low or iso or high

TSGCT, tenosynovial giant cell tumor, WI; weighted image, T2*: T2 star, MRI; magnetic resonance imaging.

signal intensity on T2-weighted images. TSGCTs had low to intermediate signal intensities on T1- and T2-weighted images in most cases. On the T2*-weighted images, TSGCTs had three distinct signal intensities, including low, iso, or high in comparison to muscle (Table 2).

To distinguish from muscle, T2*-weighted imaging was useful in the cases where the TSGCTs had low signal intensity. To identify subcutaneous fat, T1- or T2-weighted imaging was useful, because the TSGCTs had low to intermediate signal intensity, while subcutaneous fat tissue had high signal intensity (Fig. 2). To distinguish joint fluid, T2-weighted imaging was useful, because fluid is characterized by high signal intensity (Fig. 3). Since large joints can have adjacent muscle and joint fluid, both T2*- and T2-weighted images are useful to distinguish these various tissue types. Alternatively, because the fingers and toes have less adjacent muscle but are close to subcutaneous fat, the T1- and T2-weighted images are more important (Figs. 4 and 5). The MRI sequences that are useful to distinguish the different tissue types are listed in Table 3.

4. Discussion

Regardless of the classification for localized versus diffuse, both types of TSGCT are actually the same entity, with a tendency towards diffuse in the large joints of the knee and ankle, and localized in the small joints of the fingers and toes. This study included 10 diffuse subtype (43 %) and 13 localized (57 %) TSGCTs. In a previous study, diffuse subtypes were more common than localized subtypes [7], although there is no clear definition to distinguish diffuse from localized TSGCTs.

In order to accurately resect the lesion, clarification of the extension from normal tissue is important. T2-weighted imaging is important to distinguish TSGCTs located within the joint. This is because these

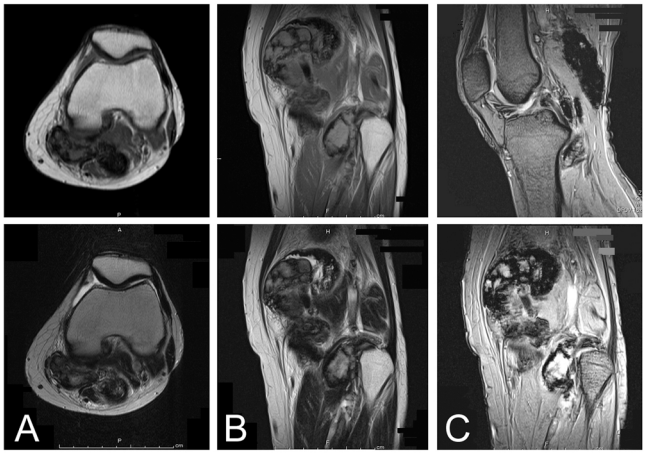

Fig. 2. A 66-year-old female with a diffuse tenosynovial giant cell tumor in the knee. The lesion has low to intermediate signal intensity on T1 (A-top; axial [TR 743.79 ms, TE 20 ms], B-top; coronal [TR 1800 ms, TE 18 ms]) and T2 (A-bottom; axial [TR 4158.09 ms, TE 100 ms], B-bottom; coronal [TR 3900 ms, TE 105 ms]) images. The T2*-weighted image is useful to distinguish the lesion from muscle, because the lesion has low intensity and muscle is iso-intensity (C-top; sagittal [TR 520 ms, TE 15 ms], C-bottom; coronal [TR 470 ms, TE 15 ms]). (Canon Medical Systems: EXCELART Vantage Powered by Atlas).

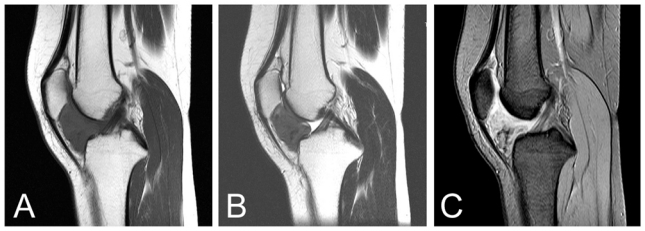

Fig. 3. A 26-year-old female with a diffuse tenosynovial giant cell tumor in the knee. The lesion is located within the joint and the margin is clear compared to the surrounding fat. However, the margin is not clear compared to the fluid on the T1-weighted image (A; sagittal [TR 500 ms, TE 17 ms]). The margin compared to the surrounding fat as well as the fluid is clear on the T2-weighted image (B; sagittal [TR 3279 ms, TE 100 ms]). The margin of the lesion compared to the surrounding fat and fluid is not clear on the T2*-weighted image (C; sagittal [TR 400 ms, TE 13.81 mg]). (Philips: INGINIA).

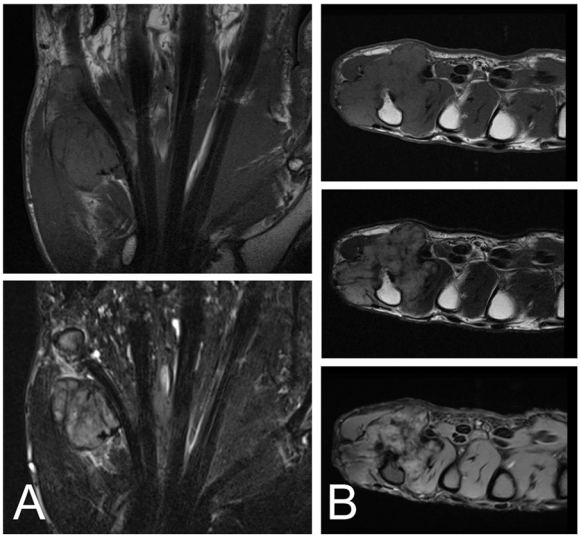

Fig. 4. A 62-year-old female with a localized tenosynovial giant cell tumor in the hand. The lesion is iso intense on the T1-weighted image (A-top; coronal [TR 450 ms, TE 15 ms], B-top; axial [TR 495 ms, TE 15 ms]) and has low to high signal intensity on the T2-weighted image (A-bottom; axial STIR [TR 4000 ms, TE 90 ms], B-middle; axial [TR 4000 ms, TE 88 ms]). The lesion has low to iso signal intensity on the T2*- weighted image, which is similar to subcutaneous tissue and muscle (B-bottom; axial [TR 623 ms, TE 20 ms]). (Siemens, MAGNETOM).

TSGCTs need to be differentiated from joint fluid. The margins of the lesions within the joints are not clear in T1- and T2*weighted imaging. T1- or T2-weighted imaging is useful for TSGCTs adjacent to the small joints of the fingers and toes. Fingers and toes have less muscle and, thus a greater need to differentiate the lesion from subcutaneous fat. Therefore, T1- or T2-weighted imaging is important for these tumor types. For TSGCTs in the small joints, the lesion needs to be differentiated from the tendon. Tendons have a low signal intensity on T1 and T2-weighted imaging, which might be similar to the lesion. However, anatomical information can help to distinguish the lesion from the tendon.

In the current study, T2*-weighted images were analyzed for detection of the lesion and its extension. The T2*-weighted imaging signal intensity of TSGCTs was found to have three distinct patterns of low, iso, and high intensity relative to muscle. The low signal intensity was useful to distinguish the lesion from muscle, however the area varied depending on the case. With TSGCTs, multiple lesions are occasionally observed. T2*-weighted imaging is useful to detect lesions in muscle, because T1- and T2-weighted images fail to detect such lesions. T2*-weighted imaging is useful in TSGCTs of the large joints, because

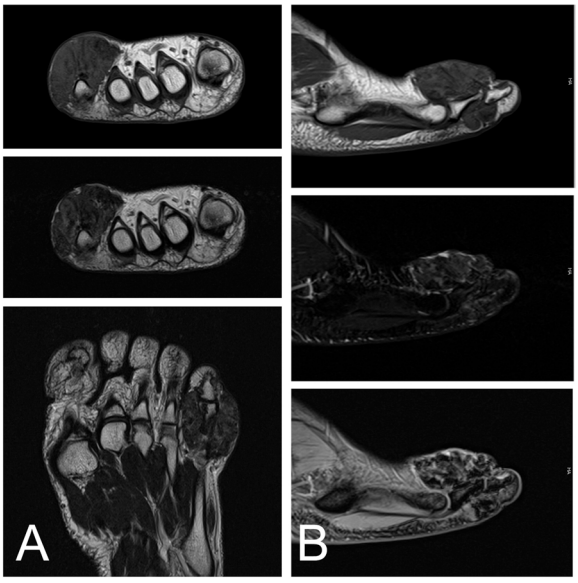

Fig. 5. A 31-year-old male with a localized tenosynovial giant cell tumor in the toe. The lesion has low signal intensity on the T1-weighted image (A-top; axial [TR 450 ms, TE 12 ms], B-top; sagittal [TR 441 ms, TE 12 ms]), and the T2-weighed image (A-middle; axial [TR 4000 ms, TE 84 ms], A-bottom; coronal [TR 4000 ms, TE 84 ms]). The T2-weighted image with fat suppression is not useful to distinguish the lesion from surrounding tissue (B-middle; sagittal [TR 4992 ms, TE 90 ms]). The T1- and T2-weighted images can differentiate the lesion from subcutaneous tissue, while the T2*-weighted image cannot differentiate it from fat (B-bottom; sagittal [TR 700 ms, TE 15 ms]). (Canon Medical Systems: EXCELART Vantage Powered by Atlas).

Table 3
Useful MRI signal intensities to distinguish tenosynovial giant cell tumors.

Tissue	Useful sequence	Tissue signal	TSGCT signal
Muscle	T2*-WI	iso	low or high on T2*-WI
Fat	T1- or T2-WI	high	low on T1- or T2-WI
Fluid	T2-WI	high	low on T2-WI

TSGCT, tenosynovial giant cell tumor; MRI, magnetic resonance imaging; WI, weighted image; T2*, T2 star.

these tumors are located within deep tissue and are characterized by surrounding muscle. High signal intensity regions on T2*-weighted imaging were seen in almost half of the cases. The high signal intensity seems characteristic of TSGCTs, but the meaning of the high signal intensities on T2*-weighted imaging is not well documented.

5. Conclusions

In the current study, the characteristics of the MRI signal intensities in cases with TSGCTs were analyzed. The signal intensities of TSGCTs on T1- and T2-weighted images are similar to those of muscle. T2*-weighted imaging was useful to distinguish the lesion from muscle, particularly in large joints. T1- or T2-weighted imaging was useful to distinguish the lesion from subcutaneous fat tissue in small joints. Intra-articular lesions could be detected on T2-weighted images as high intensity compared to fluid and iso intensity for TSGCTs. T1, T2, and T2*-weighted MR images are useful in a tissue-specific manner for identification of tumor location, and assessment of the tumor extension, which is important for surgical planning.

CRediT authorship contribution statement

Sakamoto Akio: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Noguchi Takashi:** Formal analysis, Investigation, Methodology, Writing – review & editing. **Matsuda Shuichi:** Investigation, Supervision, Writing – review & editing.

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Ethical statement

The Institutional Review Board approved this retrospective study. The need for written informed consent was waived.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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