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SCIENTIFIC ARTICLE

Treatment-related alterations of imaging findings in osteoid osteoma after percutaneous radiofrequency ablation

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Abstract

Objectives We aimed to report the long-term outcomes of osteoid osteoma patients and to determine CT and dynamic contrast-enhanced MR imaging characteristics of radiofrequency ablation (RFA) treatment related changes of osteoid osteoma between follow-up periods.

Materials and methods Thirty patients (seven female, 23 male) who underwent CT-guided RFA of osteoid osteoma were included. Follow-up imaging examinations were divided into two subgroups; first (1–3 months) and second (> 6 months) periods. Nidus size, calcification, cortical thickening, maximum signal intensity (SImax), time of SImax (Tmax), slope of signal intensity-time (SIT) curves were noted. CT and dynamic MR imaging findings were compared between follow-up periods.

Results Clinical success rate was 100%. The mean of OO nidi size was 5.85 ± 1.98 mm before treatment. There was a significant difference for OO nidi sizes between pretreatment and second follow-up period examinations ($p = 0.002$). SImax and slope of SIT curves of all patients (100%) showed decrease on follow-up MRIs. There was a significant decrease for SImax values between pretreatment and second follow-up period. There was a significant decrease for slope of SIT curves between pretreatment and both follow-up periods.

Conclusions RFA is an effective and safe treatment choice for osteoid osteomas. On follow-up imaging, slope of SIT curve and Tmax have the most important positive predictive value for long-term outcomes and single dynamic contrast-enhanced MRI within first 3 months after treatment may be sufficient for symptom-free patients.

Keywords Osteoid osteoma · Radiofrequency ablation · Magnetic resonance imaging · Computed tomography · Follow-up

Introduction

Osteoid osteoma (OO) is a benign bone tumor that comprises the central nidus and surrounding reactive sclerotic bony changes. It accounts for approximately 12–13.5% of benign primary bone tumors [1, 2]. OO has a predilection for the diaphysis of long bones and most commonly arises from the cortex. The tumor has male predominance and usually affects young individuals. Pain that worsens at night is the most common symptom and it responds well to the non-steroidal anti-inflammatory drugs [1–4].

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The traditional treatment option for OO is surgical resection of the tumor. However, since Rosenthal et al. [5] described it in 1992, radiofrequency ablation (RFA) has become a favorable minimal invasive treatment choice for OO. Previous studies reported high success rates [6–10]. Furthermore, this technique has advantages of lower cost and fewer complications when compared to surgery.

Recurrence of the lesion usually leads pain clinically. Many groups follow their patients based on pain assessment. Because pain assessment is a subjective method, imaging is necessary to exclude recurrence in patients with suspected/atypical pain. Treatment-related changes may be confusing in terms of imaging. At this point, it is important for radiologists to be accustomed to the imaging findings of treated OO lesions and changes secondary to RFA procedure in time.

The outcomes of RFA treatment for OO have been reported in detail in the literature. However, a few studies determined the imaging changes related to RFA treatment of OO and no study has yet evaluated the imaging changes between follow-up periods. The purposes of this study are to report the long-term outcomes of osteoid osteoma patients and to determine the dynamic contrast-enhanced MR and CT imaging characteristics of RFA treatment-related changes of OO between follow-up periods.

Materials and methods

This retrospective study was approved by our institutional review board.

Patient data From 2005 to 2017, 30 patients (seven female, 23 male) who underwent CT-guided RFA for the treatment of osteoid osteoma were included. Mean age of the patients was 15.6 years (range, 3–46 years). The duration of osteoid osteoma-related symptoms prior to RFA procedure were varied in the range between 6 and 36 months. One patient was a recurrent case after surgery. Twenty-nine patients applied for RFA as the first treatment choice.

In our institution, the patients treated with RFA were called for control imaging with CT and MRI at 1, 3, 6, and 12 months after treatment. However, the fact that many of these patients live in different cities did not enable this follow-up imaging program to be implemented regularly. Therefore, we divided the follow-up imaging periods into two subgroups. The first 1 to 3 months after RFA treatment conducted as first follow-up period, and > 6 months after RFA treatment was conducted as second follow-up period.

All patients underwent CT examinations before treatment, and first and second follow-up periods after RFA treatment. All CT examinations were performed with a 64-slice scanner (Lightspeed VCT, GE Healthcare, Milwaukee, WI, USA) unit. Scanning parameters were applied by consideration of lesion localization and the patient's age (90–120 kVp, 100–250 mAs, 0.625–3 mm slice thickness). Nidus size, presence of calcification, and cortical thickening were noted and these parameters were reevaluated on follow-up examinations.

Eighteen of 30 patients had dynamic MR imaging before treatment. Two patients did not participate in MR imaging in the first follow-up period whereas four patients did not participate in MR imaging in second follow-up period. Therefore, missing data were excluded and we evaluated MRI findings on 16 patients in the first follow-up period and on 14 patients in second follow-up period. All MRI examinations were performed on 3.0-T MRI unit (Magnetom Verio, Siemens, Erlangen, Germany). Standard T1- and T2-weighted spin-echo sequences were obtained in diagnostic quality. T1-weighted gradient echo sequence (TR: 4.29, TE: 1.47, flip angle: 9°) was used for dynamic imaging with the 35 consecutive acquisitions, each had temporal resolution of 12–15 s. The same imaging parameters were used for pretreatment and follow-up examinations. Signal intensity of the lesion before the intravenous contrast material injection (SIpre), maximum signal intensity (SImax), time of maximum signal intensity (Tmax), slope of signal intensity–time (SIT) curves were calculated and the presence of bone marrow edema was noted before and after treatment examinations. SImax was determined as the maximum value of the ascending limb of signal intensity–time curve [11]. Tmax was determined as the time from the start of dynamic imaging to SImax. Slope of the curve per minute was calculated with the formula of (SImax - SIpre) × 100 / SIpre × Tmax [12]. In addition, the decreasing rates of the curve slopes in the first and second follow-up periods were calculated according to the slope of pretreatment curve.

Current clinical data and information about the presence of osteoid osteoma-related symptoms was obtained via phone from the patients and legal carers of the patients under the age of 18 years. Patients' demographics, lesion localization, and follow-up time are summarized in Table 1.

RFA procedure All procedures were performed by a single radiologist (GE, 14 years of experience in CT-guided interventions) with CT guidance. Twenty-five patients had general anesthesia and five patients had spinal anesthesia during RFA procedure. Patients had given appropriate position depending on the lesion localization. Optimal limited scanning area including OO nidus was planned. Twenty-eight patients were approached from the shortest distance to the tumor nidus whereas two patients were approached from the opposite cortex of the tumor. In cases of significant cortical thickening, drilling was used. All procedures were performed with monopolar RF ablation electrodes (UniBlate or Starburst XL, RITA Medical Systems - Angiodynamics, Latham, NY, USA). The active tip of the RF electrode was placed within the nidus and the electrode was connected to the RF generator. Temperature was increased gradually and at 90 °C maintained for a period of 6 min.

Table 1 Data of the patients

Variables	Mean ± SD or *n*
Age (years)	15.6 ± 9.8 (range, 3–46 years)
Sex (male:female)	23:7
Follow-up time (months)	70.63 ± 41.44 (range, 12–151 months)
Lesion localization (*n*)	
Femur	19
Tibia	7
Humerus	1
Ulna	1
Iliac crest	1
Metatarsal	1

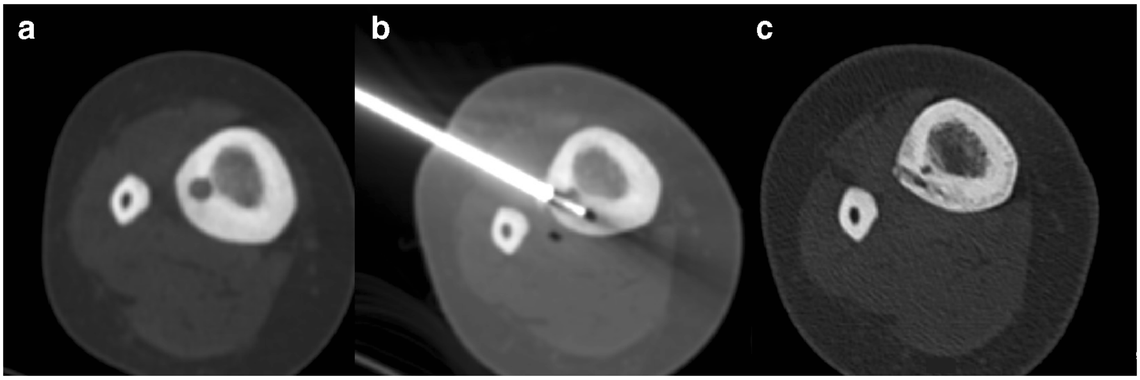

Fig. 1 Osteoid osteoma of tibial shaft without nidal calcification and accompanying prominent cortical thickening (**a**) and during RFA (**b**). Note the significant reduction of lesion size at first-year control (**c**)

Statistical analysis SPSS 22.0 software (IBM Corp, Armonk, NY, USA) was used to perform statistical analyses. Mean, standard deviation, minimum and maximum values composed the descriptive statistics. Wilcoxon signed-ranks test was used to compare variables that were obtained from both CT and MR images. A P value of < 0.05 was considered statistically significant.

Results No patients had any complaint that could be related to OO, since after RFA treatment. Therefore, our clinical success rate was 100%. The mean of OO nidi size was 5.85 ± 1.98 mm on pretreatment examinations. There was no visible nidus for five (16%) patients on follow-up CT examinations after RFA treatment. The nidus sizes of 22 (73%) patients were decreased after RFA treatment on second follow-up period examinations (Fig. 1). The mean of OO nidi sizes for the first and second follow-up periods were 5.19 and 3.48 mm, respectively. There was a significant difference for OO nidi sizes between pretreatment and second follow-up period examinations ($p = 0.002$). Eighteen (60%) patients had calcification within the OO nidus. There were no significant differences for calcification sizes between pretreatment and follow-up examinations.

Twenty-six patients demonstrated accompanying cortical thickening to OO nidi on pretreatment examinations. The mean cortical thickening was 8.78 ± 6.06 mm. Cortical thickening remained stable for 22 (84%) of 26 patients on both early and late posttreatment follow-up examinations. In comparison to pretreatment examinations, cortical thickening demonstrated a slight decrease for three patients on the first follow-up period, and four patients on the second follow-up period examinations (Fig. 2). There was no statistically significant difference for cortical thickening between pre and posttreatment examinations. Table 2 summarizes the measurements of pre and posttreatment CT examinations.

Eighteen patients (100%) who had MRI before RFA treatment demonstrated bone marrow edema accompanying OO nidus. Bone marrow edema was resolved in eight patients in first follow-up period, and in ten patients in second follow-up period after RFA treatment (Fig. 3). SImax of all patients (100%) showed decrease on follow-up MRIs. There was a significant decrease for SImax values between pretreatment and the second follow-up period ($p = 0.008$). The mean Tmax values of OO for pretreatment, first and second follow-up periods were 65.5, 95, and 147 s, respectively.

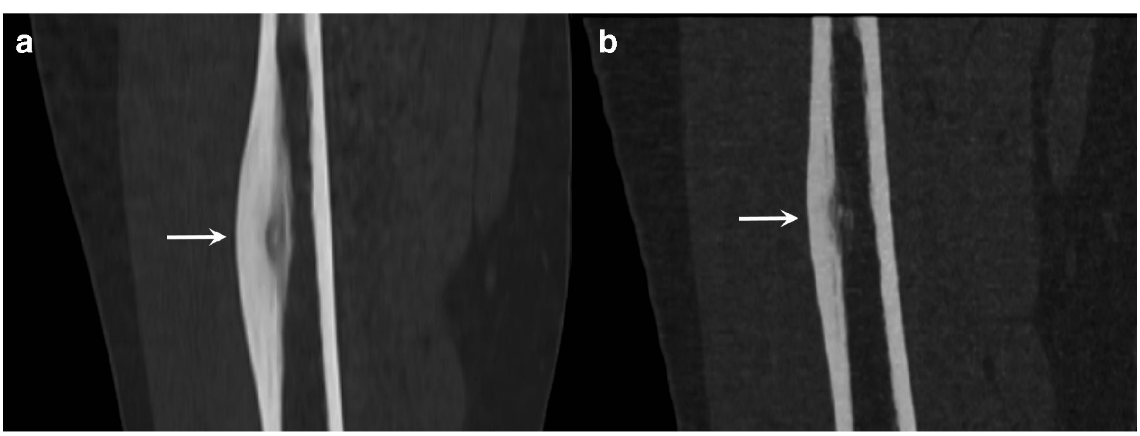

Fig. 2 A 12-year-old female patient with osteoid osteoma at right femur diaphysis. Coronal CT images of pretreatment (**a**), and posttreatment (**b**, 1st year), respectively. The accompanying cortical thickening to osteoid osteoma nidus was decreased after treatment on follow-up examination (*arrow*)

Table 2 Measurements of patients for pre and post-treatment CT examinations

Parameter	Pre-treatment	Follow-up periods	
		First	Second
Nidus size (mm)	5.85 ± 1.96	5.19 ± 2.38	3.48 ± 2.88
Calcification size (mm)[a]	1.81 ± 1.80	1.72 ± 1.55	1.39 ± 1.38
Cortical thickening (mm)[b]	8.78 ± 6.06	8.64 ± 6.03	8.57 ± 6.09

[a] Calcification size was evaluated on 18 patients

[b] Cortical thickening was evaluated on 26 patients

There were significant extensions for Tmax values between pretreatment and both follow-up periods. Slope of SIT curves of all patients (100%) showed decrease on follow-up MRIs. The mean slope of SIT curves was 195.7% before treatment. There was a significant decrease for slope of SIT curves between pretreatment and both follow-up periods (Fig. 4). However, no significant difference was found for slope of SIT curves between the first and second follow-up periods ($p = 0.386$). The slope-decreasing rates were found similar in both follow-up periods, and no significant difference was found for slope-decreasing rates between two follow-up periods. The measurements obtained from dynamic MRI of patients for pre and post-treatment examinations are summarized in Table 3.

Discussion

The success rates of RFA treatment for OO varied between 67 and 100% in the literature [13, 14]. In our study, no patients had any symptoms that could be related to OO after RFA treatment during long-term follow-up, and our success rate was 100%. However, success rates in the studies involving a relatively large number of patients may be more reliable.

Mahnken et al. [15] studied contrast-enhanced MRI the day after RFA treatment for osteoid osteoma and reported that with the lesions which illustrate an increase of a signal-to-noise ratio of more than 20% after contrast material injection, these patients might be considered candidates for re-ablation even if they were asymptomatic to avoid symptomatic recurrence. In the present study, MR imaging after RFA treatment for OO demonstrated that OO nidi continue to enhance on posttreatment MRI. However, the slope of SIT curves significantly decreased on both follow-up periods after RFA treatment in comparison to pretreatment MRI. Therefore, a decrease in slope of SIT curve may be more useful in predicting long-term outcomes of RFA treatment and in avoiding unnecessary interventions.

Teixeira et al. [16] evaluated the relationship between the outcomes of laser thermal ablation treatment for osteoid osteoma and perfusion MRI parameters. In that study, the authors reported that successfully treated osteoid

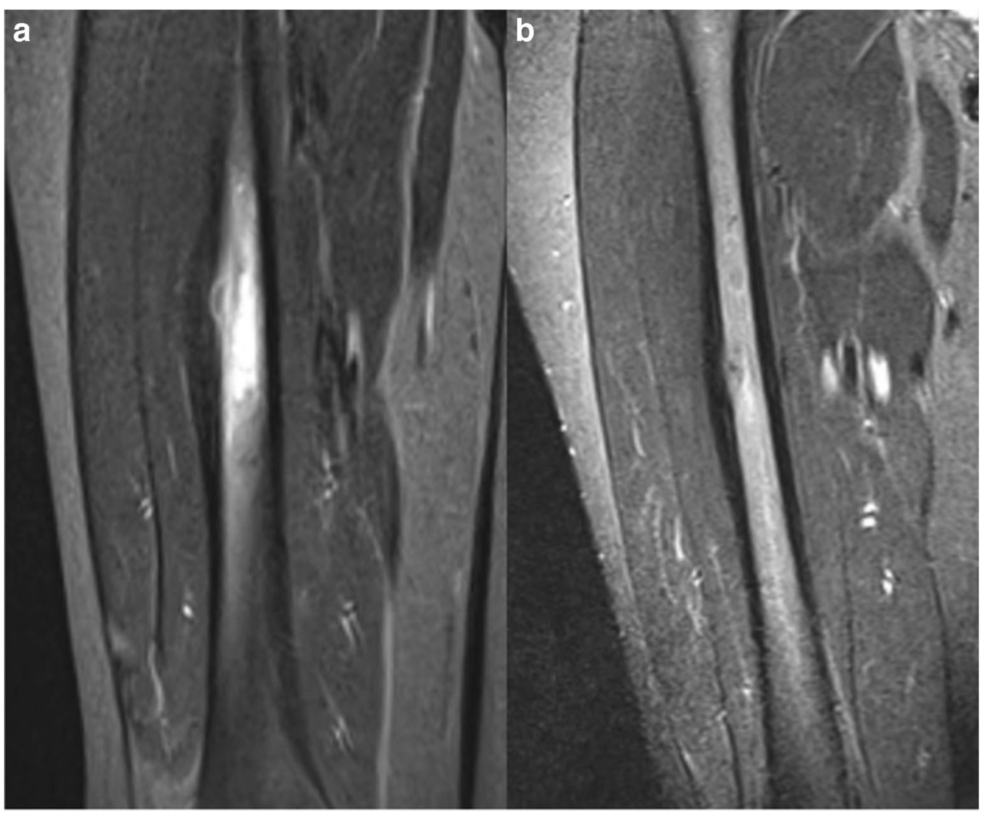

Fig. 3 A 12-year-old female patient with osteoid osteoma at right femur diaphysis. Coronal short tau inversion recovery (STIR) images of pretreatment (**a**), and posttreatment (**b**, 1st year), respectively. Images demonstrated that accompanying bone marrow edema resolved markedly after treatment on follow-up examination

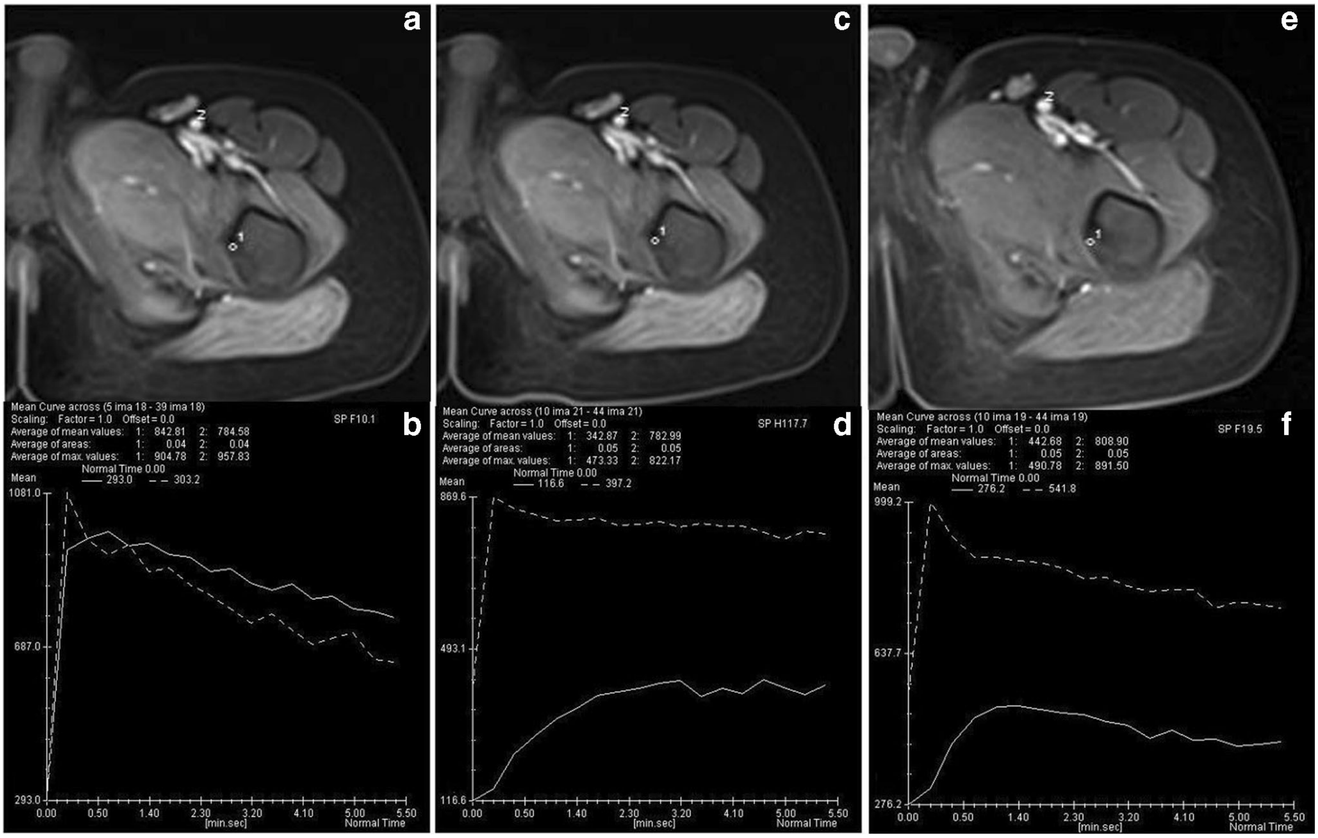

Fig. 4 A 6-year-old male patient with osteoid osteoma at left femur. Contrast-enhanced T1-weighted fat-suppressed (**a**, **c**, **e**) and signal intensity–time curves (**b**, **d**, **f**) of pretreatment, first and second follow-up periods, respectively. Images demonstrated that slope of the osteoid osteoma nidus decreased markedly after treatment on follow-up examinations. (The *straight line* represents the osteoid osteoma nidus and the *dotted line* represents the superficial femoral artery)

osteoma lesions demonstrated extension of mean time to peak (pretreatment: 79.4 and posttreatment: 182.2), and 40.5% drop of slope of the SIT curves. These parameters were significantly different between those treated successfully and those with treatment failure. Our results were consistent with the results of that study. In the present study, all patients treated successfully with RFA and pretreatment and follow-up MR examinations represented significant decrease of slope of SIT curves and extension of the Tmax values. Therefore, our results support that the slope of the SIT curve and Tmax are the most important parameters for predicting the long-term outcome of ablative therapies for osteoid osteoma.

Although none of our patients had recurrence or unsuccessful treatment procedure, depending on previously published articles [15, 16] and results of current study, we may assume that patients whose osteoid osteoma nidus does not illustrate a decrease in slope of SIT curves or extension in Tmax values on post-treatment MRI may be a candidate for reablation.

Vanderschueren et al. [17] examined 86 osteoid osteoma patients by CT after thermal ablation therapy and they reported that 45 of 63 (71%) successfully treated osteoid osteoma nidi completely ossified or decreased in diameter. They also reported that 24% of osteoid osteoma nidi remained stable in diameter. In our study, 16% of osteoid osteoma nidi was not visible and 73% of all osteoid osteoma nidi were decreased in size on follow-up CT images. Our results were similar to the results of an aforementioned study. Moreover, Vanderschueren et al. [17] evaluated dynamic MRI findings of 18 patients before and after

Table 3 Dynamic MRI measurements of patients for pre and post-treatment examinations

Parameter	Pre-treatment ($n = 18$)	Follow-up periods	
		First ($n = 16$)	Second ($n = 14$)
SImax	550.5 ± 254.9	306.3 ± 176.2	264.4 ± 156.9
Tmax (s)	65.5 ± 22.2	95.0 ± 46.8	147.0 ± 54.9
Slope of SIT curve (%)	195.7 ± 70.7	53.5 ± 49.4	43.1 ± 28.2
Slope decreasing rate (%)		72.2 ± 27.11	74.2 ± 24.6

SImax maximum signal intensity, *Tmax* time of maximum signal intensity, *SIT* signal intensity-time thermal ablation therapy. According to their results, the authors suggested that an increase of delay time tends to be associated with treatment success. In our study, treatment success rate was 100%, and Tmax values were significantly extended on both follow-up periods. Therefore, our results were consistent with the authors' suggestion.

RFA is the preferred treatment option for OO worldwide, since its success and reliability have been proven. There is no consensus on the follow-up program after RFA treatment and many institutions apply their own follow-up program, which consists of several examinations for their patients. Our results revealed that there is no significant difference on imaging findings between follow-up periods. Therefore, we may suggest that rather than conducting several examinations in follow-up of RFA-treated OO patients, establishing a single dynamic contrast-enhanced MR imaging may be sufficient in follow-up for symptom-free patients due to its advantages of including the most important parameters for long-term outcomes and lack of ionizing radiation. This will eliminate potential risks of radiation and gadolinium injection for repeated CT and MR examinations, respectively, as well as contribute to a reduction of costs. Further studies with a large number of patients and different follow-up periods are warranted.

Treatment-related changes may be confusing in terms of imaging. It is important for radiologists to be accustomed to the imaging findings of treated OO lesion and changes secondary to RFA procedure in time.

According to our clinical observations, the longer the elapsed time after treatment, the less compliance of patients to the follow-up program. In addition, there were no significant differences for imaging findings between follow-up periods. Therefore, we think that recommendation of dynamic contrast-enhanced MR imaging within first 3 months after RFA treatment may be appropriate.

This study emphasized the predictive value of dynamic MRI parameters for treatment success and underlined sufficiency of single dynamic MR imaging after treatment according to detection of insignificant differences between follow-up periods. The main limitations of our study are retrospective design and small number of patients. Although there are many studies on outcomes of RFA treatment for osteoid osteomas with a large number of patients existing in the literature, this study has a strength on representing alterations in imaging features of treatment-related changes for osteoid osteoma. One other limitation is the lack of uniformity in imaging times for follow-up examinations. All patients were called for follow-up examinations regularly. However, we encountered difficulties in adapting the patients to a follow-up program for various reasons. We aimed to overcome this limitation by dividing the follow-up examinations into two subgroups.

In conclusion, RFA is an effective and safe treatment choice for osteoid osteomas. On follow-up imaging, the slope of the SIT curve and Tmax have the most important positive predictive value for long-term outcomes and single dynamic contrast-enhanced MRI within the first 3 months after treatment may be sufficient for symptom-free patients.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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