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# Diffusion weighted MRI of osteoid osteomas: Higher ADC values after radiofrequency ablation

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ABSTRACT

*Purpose:* Feasibility of diffusion weighted MRI (DWI) pre- and post-radiofrequency ablation (RFA) in patients with osteoid osteoma (OO).
*Material and methods:* Ten patients (1 female, 24 ± 9 years) received RFA of OO (mean size 8.7 ± 3.2 mm). Two OO recurred, in one of these a second RFA was performed. A 1.5 T DWI (b = 50, 400, and 800 s/mm$^2$) and a fat saturated DCE MRI were obtained the day before and after RFA. In DWI, the mean apparent diffusion coefficient (ADC) was recorded. With DCE MRI, signal-to-noise ratio, contrast-to-noise ratio, absolute signal intensity (SI), relative SI, and SI ratio were documented. All parameters were compared pre- and post-RFA using paired Wilcoxon rank test.
*Results:* ADC values were significantly higher post-ablation, 1.6 ± 0.5 μm$^2$/ms versus 1.3 ± 0.6 μm$^2$/ms ($p < 0.05$). Perfusion was significantly reduced after ablation [SNR, CNR, SI, %SI, and SI OO/SI muscle]; post-RFA: 55 ± 13, 27 ± 20, 757 ± 534, 102 ± 16, and 1.6 ± 0.2; pre-RFA: 88 ± 37, 65 ± 22, 1038 ± 755, 226 ± 51, and 2.0 ± 0.5 ($p < 0.05$).
*Discussion:* DWI is feasible in OO. ADC values increased and contrast enhancement decreased after RFA of OO. This may be explained by RFA-induced necrosis and devascularization.


## 1. Introduction

Since its introduction in 1992, computed tomography (CT)-guided percutaneous radiofrequency ablation (RFA) of painful osteoid osteomas (OO) evolved to the first-line therapy and almost replaced primary surgical management [1]. While the diagnosis is based on clinical symptoms and CT, magnetic resonance imaging (MRI) has its role in atypical locations and for exclusion of other bone lesions [2]. For successful therapy destruction of the tumor nidus is necessary [3]. Success rates of RFA are high, ranging from 67% to 100% [4]. In contrast to surgery where resection margins are pathologically determined, recurrence may occur even in patients who are symptom-free shortly after intervention. Post-treatment imaging as diffusion weighted imaging (DWI) could help do determine complete ablation success of OO in special localizations.

Previous studies showed a high contrast enhancement of untreated osteoid osteomas [5] while contrast enhancement decreased after ablation [3,6]. After ablation a central T1 and T2 hypodense area with a peripheral T2 hyperintense margin was observed [5,7]. The aim of this study was to assess the feasibility of DWI in OO. For comparative purpose, dynamic contrast enhanced (DCE) MRI was evaluated simultaneously.

## 2. Material and methods

Inclusion criteria for this retrospective data analysis were a clinically and radiologically confirmed OO, pre- and post-RFA diffusion weighted MRI, and lesions larger than 3 mm.

### 2.1. RFA

Written informed consent was obtained from all patients before treatment. CT-guided RFA was carried out under general anesthesia in all patients. For procedure planning, non-enhanced CT was performed (Somatom Definition, Siemens, Erlangen, Germany; slice thickness 0.75 mm, collimation 64 × 0.6, 120 kV, 70 mAs$_{eff.}$, pitch 0.8, kernel U70u). OO diameter was measured in the initial CT scan. After drilling the lesion (11G to 14G) a histologic specimen was obtained. For RFA a monopolar probe (Soloist, Boston Scientific, Marlborough, Massachusetts, USA) was used in 9 patients, while in one patient a small bipolar probe was used (ProSurge micro, Olympus, Teltow, Germany). In 5 patients ablations were performed in

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**Table 1**
Diffusion weighted MRI and dynamic contrast enhanced MRI of osteoid osteomas.

| Pat. no. | Location | Pre-RFA | | | | Post-RFA | | | | Follow-up (mo) | Recurrence[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ADC ($\mu m^2/s$) | SNR | OO SI/SI% | Muscle SI/%SI | SI Ratio[c] | ADC ($\mu m^2/s$) | SNR | OO SI/SI% | Muscle SI/%SI | SI Ratio[c] | | |
| 1[b] | 3. *meta*-carpal | 1972 | 123 | 846/207 | 420/132 | 2.0 | 1798 | 76 | 394/100 | 224/107 | 1.8 | 1 | no |
| 2, RFA1 | Tibia, syndes-mosis | 1388 | NA | NA | NA | NA | 1489 | NA | NA | NA | NA | 23 | yes |
| 2, RFA2 | Tibia, syndes-mosis | 1853 | 72 | 1293/209 | 480/178 | 2.7 | 2158 | 68 | 1218/119 | 814/101 | 1.5 | 4 | no |
| 3 | Tibia | 1053 | 86 | 2861/289 | 1143/125 | 2.5 | 1313 | 52 | 1632/102 | 899/99 | 1.8 | 5 | no |
| 4 | Talus | 1723 | 58 | 1367/170 | 824/104 | 1.7 | 1876 | 57 | 1145/104 | 689/81 | 1.7 | 10 | no |
| 5 | Tibia, syndes-mosis | 1173 | 91 | 1767/261 | 796/110 | 2.2 | 2528 | 55 | 1314/106 | 902/116 | 1.5 | 13 | yes |
| 6 | 5. cervical vertebra | 1328 | 69 | 905/316 | 371/98 | 2.4 | 1332 | 56 | 715/96 | 509/120 | 1.4 | 14 | no |
| 7 | Tibia | 1072 | 36 | 1001/164 | 707/105 | 1.4 | 1350 | 46 | 216/126 | 120/109 | 1.8 | 16 | no |
| 8 | Calcaneus | 1274 | 115 | 654/240 | 384/112 | 1.7 | 1287 | 68 | 475/101 | 173/123 | 1.2 | 19 | no |
| 9 | Femur | 381 | 162 | 211/174 | 156/119 | 1.4 | 270 | 35 | 45/65 | 232/93 | 0.3 | 19 | no |
| 10 | Femur | 646 | 68 | 475/235 | 238/114 | 2.0 | 1998 | 40 | 417/102 | 204/110 | 1.8 | 19 | no |
| mean | | 1261 ± 484* | 88 ± 37* | 1038 ± 755[a]/226 ± 51[a] | 552 ± 307/119 ± 23 | 2.0 ± 0.5* | 1582 ± 595* | 55 ± 13[a] | 757 ± 534[a]/102 ± 16[a] | 476 ± 323/106 ± 13 | 1.6 ± 0.2* | 13 ± 7 | 2 |

ADC apparent diffusion coefficient, SNR signal-to-noise Ratio, OO osteoid osteoma, SI signal intensitiy, % SI relative SI.
* significance in paired Wilcoxon rank test, pre-/post-RFA, $p < 0.05$.
[a] <0.01.
[b] Bipolar Celon probe.
[c] SI of OO divided by SI of muscle.
[d] Clinical syptoms.

two positions during the same procedure. All ablations were performed according to the vendor's application protocol.

### 2.2. MRI

Three dimensional MR imaging was performed at 1.5 T one day before RFA (0.9 ± 0.3 days) and on the day after RFA (1.1 ± 0.3 days) (Magnetom Espree, Siemens, Erlangen, Germany) for diagnosis of OO and for routine follow-up to exclude post-intervention complications. For each body region dedicated phased array coils were used. Routine proton weighted, T1-weighted SE, and T2-weigted TSE images were obtained. Axial single-shot spin-echo echo-planar (SS-EPI) diffusion weighted sequence was applied with three b-values; 50, 400, and 800 s/mm$^2$, voxel size 2 × 3.3 × 3.3 mm$^3$, TR 4482 ms, TE 102 ms, flip angle 90°, gradients in 3 orthogonal directions, 4 averages, band width 1395 Hz, 96 phase encoding steps. ADC maps were calculated using means of each b-value. ADC of OO was measured by free hand placed regions of interest (ROI) in $\mu m^2/s$ (IMPAX EE, Agfa Health Care, Bonn, Germany). Axial spectral fat saturated dynamic enhanced T1 image sets were obtained using Gadopentetat-Dimeglumin (Gadovist, Bayer Healthcare, Leverkusen, Germany) with a dose of 0.1 ml/kg body weight injected at 1 ml/s followed by a 15 ml saline chase bolus; slice thickness 2 mm, TR 5.2 ms, TE 1.8 mse, flip angle 10°, band width 347 Hz, 165 phase encoding steps; 10 image sets with repetition rate dependent on the body region ranging from 12 to 30 ms. Imaging parameters on pre- and postprocedural MR imaging were kept constant for each patient. Free hand ROIs with the size of 4–8 voxels were placed in the OO, the adjacent bone, the distant bone, muscle and the image background. ROI size was kept constant in pre- and post-RFA images. Enhancement diagrams were drawn. Subtraction images were computed (unenhanced Images − contrast enhanced images at the time of maximal enhancement). After semiautomatic registration procedure at a dedicated work station (MMWP 2008, software version VE31A, Siemens, Erlangen, Germany), subtraction pre- and post-RFA image sets were computed to visualize changes in perfusion.

### 2.3. Statistical analysis

Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated: SNR = signal intensity (SI) of OO divided by background SI; CNR = SI of OO subtracted by SI of the adjacent healthy bone then divided by background SI. Additionally, SNR-ratio was calculated: $SNR_{post\text{-}RFA}/SNR_{pre\text{-}RFA}$. The SI ratio of OO and muscle were computed similar to the analyses of Kostrzewa et al. [3]. Wilcoxon's rank test for paired samples was calculated for comparison of ADC, SNR, CNR, SI, % SI and SI ratio before and after RFA using SPSS® (version 21, IBM, Armonk, USA). Follow-up data were obtained via phone call (mean 13 ± 7 months after RFA). Special attention was paid to patients with recurrent OO with persistent symptoms. Salient findings of recurrent patients were documented in a descriptive manner. A p-value of <0.05 was considered significant. Data are expressed as means ± standard deviations.

## 3. Results

A total of 10 patients (9 male, 1 female; 24 ± 9 years) fulfilled the inclusion criteria and were included in this retrospective data analysis. OOs were located in the tibia (n = 4), the femur (n = 2), carpal bones (n = 1), tarsal bones (n = 2), and cervical (n = 1); mean lesion size was 8.7 ± 3.2 mm. Eight lesions were histologically proven, while histology was inconclusive in two cases. Two patients with proven OO had recurrent symptoms. One of these received re-intervention in the timespan of the study. This patient had no DCE MRI data set before and after the first intervention. The second