Original Article

Osteoid osteoma: treatment outcome and long-term follow-up after MRI-guided laser ablation

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Background: Aim of this study was to investigate short-term and long-term treatment outcome, complication rates, and patient satisfaction after MRI-guided laser ablation (LA) of osteoid osteoma (OO).

Methods: Thirty-five patients with OO in typical and atypical localizations were treated by MRI-guided LA with MRI thermometry in an open 1.0 T system. Twenty-nine patients underwent a standardized telephone interview including questions about recurrence, residual pain or functional symptoms, and satisfaction for short-term follow-up after a mean of 31 months. Twenty-one of these patients were available for long-term telephone follow-up after a mean of 116 months.

Results: Technical success of MRI-guided LA was 100% without major complications. Two minor complications included transient local inflammation and transient damage of the peroneal nerve associated with improper patient positioning during the procedure. Primary clinical success was 92% (11/12) in typically located OO and 82% (14/17) in atypically located OO. Secondary clinical success after repeat ablation was 100% regardless of OO location. Patient satisfaction and acceptance of the intervention were very good at both short-term (97%) and long-term (100%) follow-up.

Conclusions: MRI-guided LA of OO is a safe and effective treatment option resulting in high short-term and long-term patient satisfaction and acceptance rates. Recurrence and adverse events were more common in patients with atypically located OO. Level of Evidence: Level 3, non-randomized follow-up study.

Keywords: Osteoid osteoma (OO); interventional MRI; interventional radiology; thermal ablation; long-term outcome

Submitted Jun 28, 2021. Accepted for publication Oct 12, 2021.
doi: 10.21037/atm-21-3343
View this article at: https://dx.doi.org/10.21037/atm-21-3343

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Introduction

Osteoid osteoma (OO) is a benign osteoblastic neoplasm that usually occurs in the first three decades of life and commonly causes nocturnal pain responding to nonsteroidal anti-inflammatory drugs (NSAID) such as acetylsalicylic acid (1-3). OO most frequently affects long bones like the femur or tibia. In contrast to this "typical" localization, OO are referred to as "atypical" or "technically challenging" when found in spinal column, shoulder girdle, and pelvis (trunk skeleton) or small bones of the distal extremities (2,4-6).

In the last decades, treatment of OO has shifted towards minimally invasive methods such as image-guided thermal ablation (7,8). Open surgical resection plays a subordinate role (8,9). With regard to nonsurgical focal therapies for OOs, several options exist. Mainly due to its wide availability and familiarity, CT-guided radiofrequency ablation (RFA) has become the treatment of choice with very good success rates, few complications, and high patient satisfaction in several clinical studies (6,10-15). However, as an alternative for image guidance, MRI offers potential advantages, such as better visualization of structures at risk and real-time temperature monitoring during thermal procedures (16,17). In addition, various primary thermal ablation procedures exist. RFA has been used the longest, and more recently microwave ablation (MWA) and cryoablation have also been used, each with specific advantages and disadvantages (18). Combined with MRI-guidance, high intensity focused ultrasound (HIFU) also offers an alternative, especially in children (19,20).

In this study, the combination of MRI guidance and laser ablation (LA) was investigated which offers possible advantages, e.g., MRI and laser have no interferences enabling online MR thermometry or laser showing cost advantages over RFA (21). Little data is available on MRI guidance and the potential of MRI thermometry during LA in the treatment of OO (7,22,23). In addition, most studies have been conducted with relatively short follow-up periods (14). The aim of the present study was to fill this gap and to investigate MRI-guided LA of OO in terms of treatment outcome, complications, and patient satisfaction at short-term and long-term follow-up.

We present the following article in accordance with the MDAR reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-21-3343/rc).

Methods

Study population

This was a retrospective single-center study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Institutional Ethics Committee of Charité – University Medicine Berlin (No. EA1/301/12) and individual consent for this retrospective analysis was waived. Thirty-five patients with diagnosed OO were treated by MRI-guided LA in our clinic between June 2008 and July 2013.

Twenty-nine patients took part in a standardized telephone interview for short-term follow-up after a mean of 31±14 months (3-year follow-up) and were included in this study. Twenty-one of those patients were available for a second telephone interview for long-term follow-up after a mean of 116±13 months (10-year follow-up). Of the initial 35 patients, 6 were lost to short-term follow-up, and another 8 were lost to long-term follow-up (one patient died of a cause unrelated to the study, 7 moved to an unknown address/did not give consent) (see *Figure 1*).

Primary endpoints included technical success (defined as interventional procedure successfully executed with the applicator reaching the target position with MRI guidance) as well as primary and secondary clinical success (defined as freedom from pain and/or residual symptoms after single or repeated ablation). *Secondary endpoints* were adverse events, patient satisfaction, and acceptance of the procedure.

Interventional procedure

The interventional procedure was described in detail earlier. For photographic documentation of interventional set-up, see *Figure 2*. The interventions were performed under general and local anesthesia (cutaneous and periosteal) in an open 1.0T MRI system (Panorama HFO, Philips, Best, Netherlands) for MRI-guided percutaneous LA. Before the intervention, a single-shot intravenous antibiotic (1.5 g cefuroxime) was administered for infection prophylaxis. The MRI-guided LA technique consists of three main steps: (I) Multiplanar real-time MRI guidance: for real-time interactive lesion localization, instrument guidance, drilling, and positioning of the laser fiber within the lesion, a fast T1-weighted turbo spin echo (TSE) sequence [echo time (TE)/repetition time (TR) 5.7/200 ms, turbo factor (TF) 7, flip angle (FA) 90°, scan duration 3 s] was acquired. Full anatomical orientation was achieved by multiplanar

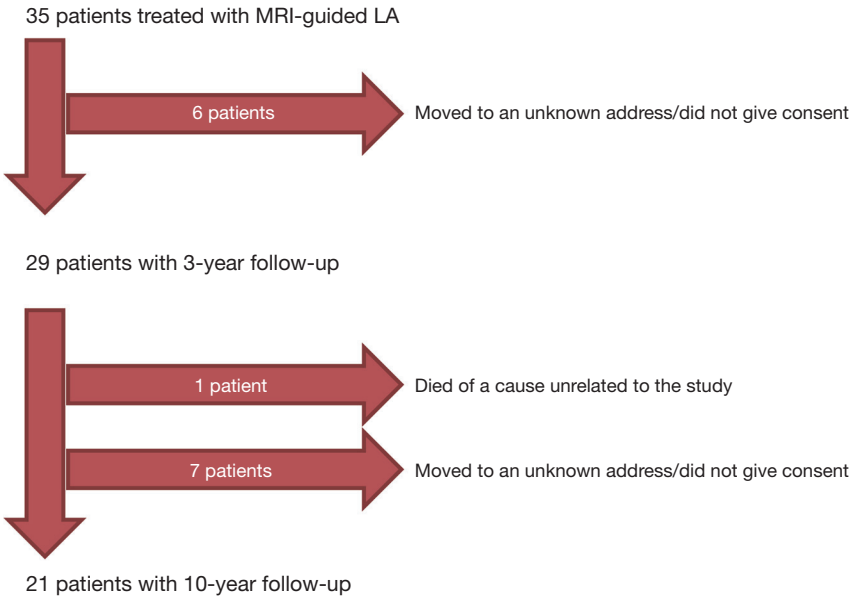


Figure 1 Patients included for follow-up. LA, laser ablation.

Figure 2 View of the interventional set up in the MRI scanner room. A 64-year-old female patient with OO of the right talus as presented in *Figure 3*. The patient is positioned in the open high-field MRI with lower extremity placed in the magnet's iso-center. Real-time MRI guidance ensures correct introduction of the laser probe. Note additional monitoring of instrument positioning and laser release during intervention. OO, osteoid osteoma.

imaging [including (para-)axial, (para-)sagittal, and (para-) coronal]. Depending on the extent of perifocal ossification and localization of the target lesion, an MRI-compatible bone biopsy drill (Invivo, Schwerin, Germany) was used to prepare the puncture tract before a 16–18 G needle (Somatex, Teltow, Germany) was introduced. A proton density-weighted (PDw) TSE sequence (TE/TR 30/383 ms, TF 11, FA 90°, scan duration 41 s) in two planes was used to verify correct needle positioning. (II) LA with online MRI thermometry: after introduction of a 600 µm bare laser fiber (Frank Optic Products®, Berlin, Germany), a Nd: YAG laser (1,064 nm, Fibertom Medilas, Dornier MedTech, Wessling,

Table 1 Patient characteristics and localizations of OO

Patient characteristics	Data
Patients treated with MR-guided LA (n)	35
Patients included in follow-up (n)	29
Sex (w; m)	9; 20
Age (years), median (range; IQR)	24 (4–64; 22)
Follow-up 1 (n=29) (months), mean ± SD	31±14
Follow-up 2 (n=21) (months), mean ± SD	116±13
Localization (typical; atypical)	12; 17
Upper extremity (n=2)	
Humerus	1
Finger	1
Lower extremity (n=25)	
Femoral neck	5
Femoral condyle	1
Femur	4
Patella	1
Tibial head	2
Tibia	6
Fibula	1
Talus	2
Heel bone	1
Metatarsal	1
Toe	1
Acetabulum	1
Iliac bone	1

OO, osteoid osteoma; MR, magnetic resonance; LA, laser ablation; IQR, interquartile range.

Germany) with continuous energy flow and an effective output ranging from 2 to 3 W was used for subsequent treatment. Total energy deposition ranged from 360–4,300 J depending on target lesions size and localization. Online MRI thermometry was used for monitoring the temperature tissue effects utilizing a T1w gradient echo (GRE) sequence (TE/TR 2/4.3 ms; FA 27°) with 4 s update time ensuring complete and safe ablation.

(III) Post-interventional control MRI: contrast-enhanced sequences (T1w SE sequences (TE/TR 12/503 ms, FA 90°, TA 92 s) and subtraction images were used to verify therapy efficacy directly after the intervention based on signal loss in the nidus. Contrast agent (Gadovist; Bayer- Schering, Berlin, Germany) injection followed a weight-based protocol (0.1 mL/kg body weight).

All patients were observed to identify possible postinterventional complications, such as neurovascular damage, bleeding, or burns, before discharge from hospital within 48 h after the procedure.

Follow-up Imaging and Patient Interviews

To compare the extent of the ablation area with the size of the former target lesion and to detect any residual/recurrent contrast enhancement of the nidus, control imaging was performed at intervals of 3, 6, and 12 months. The standard protocol included fat-saturated T2-weighted TSE sequences (SPIR, TE/TR 60/1,600 ms, FA 90°) and contrast-enhanced sequences with subtraction images as aforementioned (24).

Short-term and long-term follow-up was performed by a structured telephone interview with the following items: clinical success (recurrence or not?), residual pain, patient satisfaction, and willingness to undergo the procedure again if necessary and indicated. The interview questionnaire was modified from Seemann *et al.* (6).

Statistical analysis

Descriptive statistical evaluation was performed with Excel (Microsoft Inc., Redmond, WA, USA) and SPSS v.26 (IBM, Armonk, NY, USA). We report absolute and relative frequencies for categorical variables and used the Shapiro-Wilk test to test for normal distribution. According to the results, mean and standard deviation (SD) are given for normally distributed interval scaled data and median, interquartile range (IQR), and range for nonnormally distributed, interval-scaled data.

Results

Patient characteristics (Table 1)

Follow-up data were collected from 29 patients, among them 9 women and 20 men (female-to-male sex ratio of 9:20). Median age at the time of intervention was 24 years (youngest patient four years, oldest patient 64 years). Twelve patients (41%) had OO in typical localization, whereas 17 patients (59%) had atypical OO. A very large

Table 2 Technical success (defined as interventional procedure successfully executed with the applicator reaching the target position with MRI guidance) and clinical success (defined as freedom from pain and/or residual symptoms after single or repeated ablation), adverse events, and patient satisfaction

Endpoints	Percentage
Primary endpoints	
Technical success	100%
Primary clinical success	86% (switch to open surgery n=2)
Secondary clinical success	100%
Secondary endpoints	
Adverse events	Minor n=2 (1 transient local inflammation, 1 transient nerval lesion)
	Major n=0
Patient satisfaction	97% after 3 years
	100% after 10 years

majority of patients, 86% (25/29), had OO of the lower extremity. The tibia was the most common site of OO in the legs (6/25). Localization of OO in the upper extremity (2/29) or trunk skeleton (2/29) was rare in our patient population.

Technical and clinical success, adverse events, and patient satisfaction (Table 2)

Technical success (defined as interventional procedure successfully executed with the applicator reaching the target position with MRI guidance) of MRI-guided LA was 100%. Primary clinical success (defined as freedom from pain and/or residual symptoms after single ablation) was 86% (25/29). For one patient with persistent pain after the first intervention who opted to be treated in a different clinic, no information on outcome was available. Three of the 29 patients (10%) had recurrence. All three recurrent OOs were located atypically. Two of these were located in the femoral neck; one of the patients underwent a second MRI-guided LA, the other underwent CT-guided RFA. The third patient with recurrence had OO located in the toe and underwent open surgery. All three patients were free of symptoms afterwards. Secondary clinical success in the patients who underwent repeat MRI-guided LA was therefore 100%.

There were no major complications, and two minor adverse events occurred, both in atypically located OO: one patient with OO in the distal phalanx of digit IV experienced a transient local inflammatory reaction. One patient with OO located in the proximal femur suffered a transient lesion of the peroneal nerve most likely attributable to malpositioning and pressure on the nerve during the procedure, which resolved over time. Altogether, recurrence of OO or primary clinical failure as well as development of adverse events were more likely to occur in patients with atypical OO. For illustration, see *Figure 3* and *Figure 5* for atypical location of OO, *Figure 4* for typical location, and *Video 1* showing online MRI thermometry.

The follow-up interviews revealed a high level of patient satisfaction and acceptance of the procedure both at short-term follow-up (97% of patients satisfied) and long-term follow-up (100% of patients satisfied). The readiness to undergo MRI-guided LA again if necessary was stated by 97% at short-term follow-up and by all patients (100%) interviewed at long-term follow-up.

Discussion

OO treatment strategies have changed over the years, and image-guided local ablative procedures are now the method of choice (14,25). Besides cryoablation, hyperthermal techniques such as RFA, LA and MWA allow precise tumor ablation with high success rates while being less invasive and having fewer complications than open surgery (6,10,13,14,26,27).

Although there are cost disadvantages compared with LA (21), RFA is commonly used (14). CT is still the most common imaging modality for puncture guidance in minimally invasive OO treatment (28), but MRI guidance has also proven to be feasible in open or wide-bore MRI scanners, providing adequate patient access as well as high-quality imaging for lesion localization and instrument guidance (7). Further advantages of MRI include multiplanar navigation capabilities, online temperature monitoring during treatment (MRI thermometry), and immediate postinterventional verification of treatment success (6,7,24,29,30).

CT navigation for ablations is more widely available compared with MRI and has cost advantages. However, since OOs are regularly treated in younger patients, radiation exposure should be kept as low as possible in accordance with the ALARA (as low as reasonably achievable) principle. Especially if OO occur in the pelvic skeleton, radiation exposure resulting from CT guidance

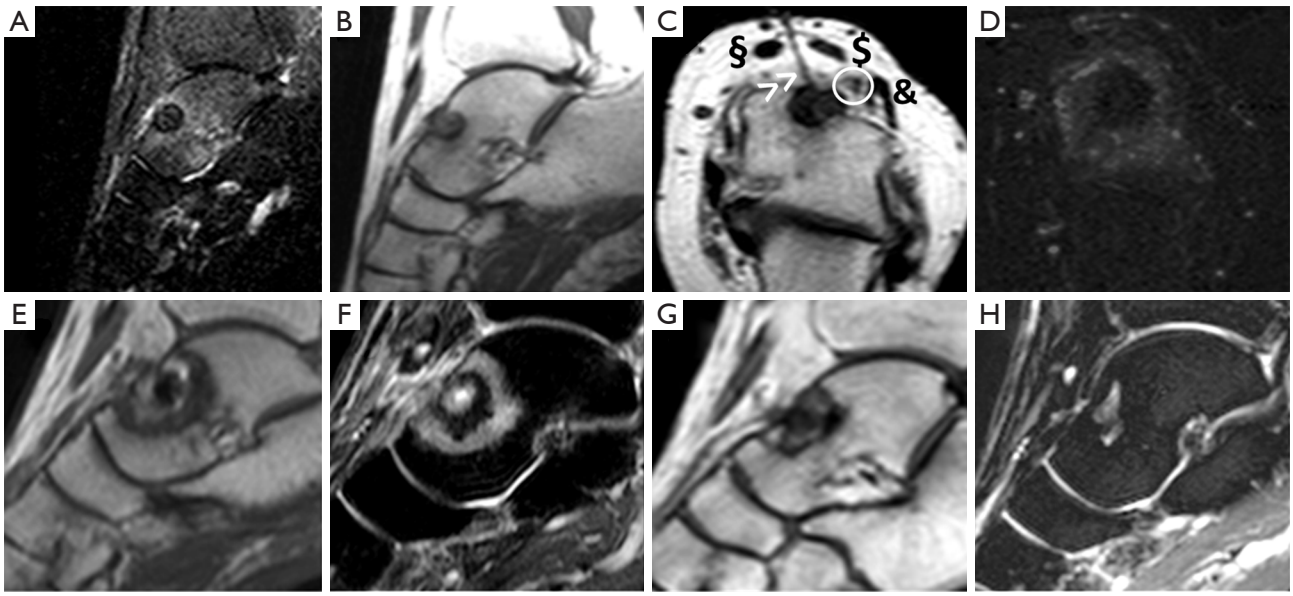


Figure 3 A 64-year-old female patient with OO of the right talus (atypical localization) presenting with pain associated with weight-bearing. Technical and clinical success, no complications. Preprocedural SPIR (A) and T1w (B) sequences in sagittal planes show osteoid osteoma of the talus. Periprocedural verification of instrument placement in axial plane (C). Immediate postablational subtraction imaging shows no residual nidal enhancement while showing a reactive perinidal enhancing rim (D). Follow-up imaging reveals typical target-sign appearance 3 months after the procedure in T1w (E) and SPIR (F) images. Further follow-up imaging reveals shrinkage of the postablational lesion and its different zonal compartments after 6 months ("positive inward fusion"), (G). Thirty-six months after the procedure, zonal differentiation has vanished; an irregularly shaped, hyperintense signal most likely represents residual scar tissue in the SPIR sequence (H). >>, needle; §, anterior tibial tendon; $, tendon of extensor hallucis longus muscle; &, tendon of extensor digitorum longus muscle; °, peroneus profundus nerve and dorsal pedis artery. OO, osteoid osteoma; T1w, T1 weighted; SPIR, spectral presaturation with inversion recovery.

is a concern even when state-of-the-art techniques with dose reduction (e.g., iterative reconstruction) or cone-beam CT are used (31,32). MRI guidance therefore might be a possible alternative as suggested by experience from MRI-guided HIFU (33,34). Compared with MRI-guided HIFU, MRI-guided percutaneous LA has the advantage of shorter treatment duration (14,33). On the other hand, HIFU is an entirely noninvasive method (34). Yet, in our study we did not see any wound healing disorders or infections after LA, underlining that LA of OO is safe. Furthermore, HIFU may have potential limitations like incomplete ablation or collateral damage due to movement of the target region as well as interactions or even reflections of HIFU waves by gas and bone, which may cause adverse effects (35). Both techniques—MRI-guided HIFU and MRI-guided LA of OO can be performed using real-time MRI thermometry, which allows precise monitoring of the progress of ablation and thus helps to spare structures at risk, such as nerves and vessels.

The fact that MRI-guided LA offers the possibility of direct postablational image control of outcome ("one-stop shop") can be considered another advantage of the method. Recently, dynamic contrast-enhanced MRI has also been described as a useful tool for visualization of short-term healing following thermal ablation of OO (36-38). Despite the wide range of imaging options, however, the long-term response to therapy has to be evaluated by clinical follow-up and patient-reported outcome measures, in particular subjective pain (39).

In this study, the primary clinical success of MRI-guided LA was 86%, and 100% in patients who underwent a second intervention, which is consistent with published results (6,10). In a systematic review, Shanmugasundaram *et al.* came to a calculated clinical success rate of 94.2% for LA, yet in these studies only 32% of OO were located atypically (14). In our study, recurrence of OO or primary

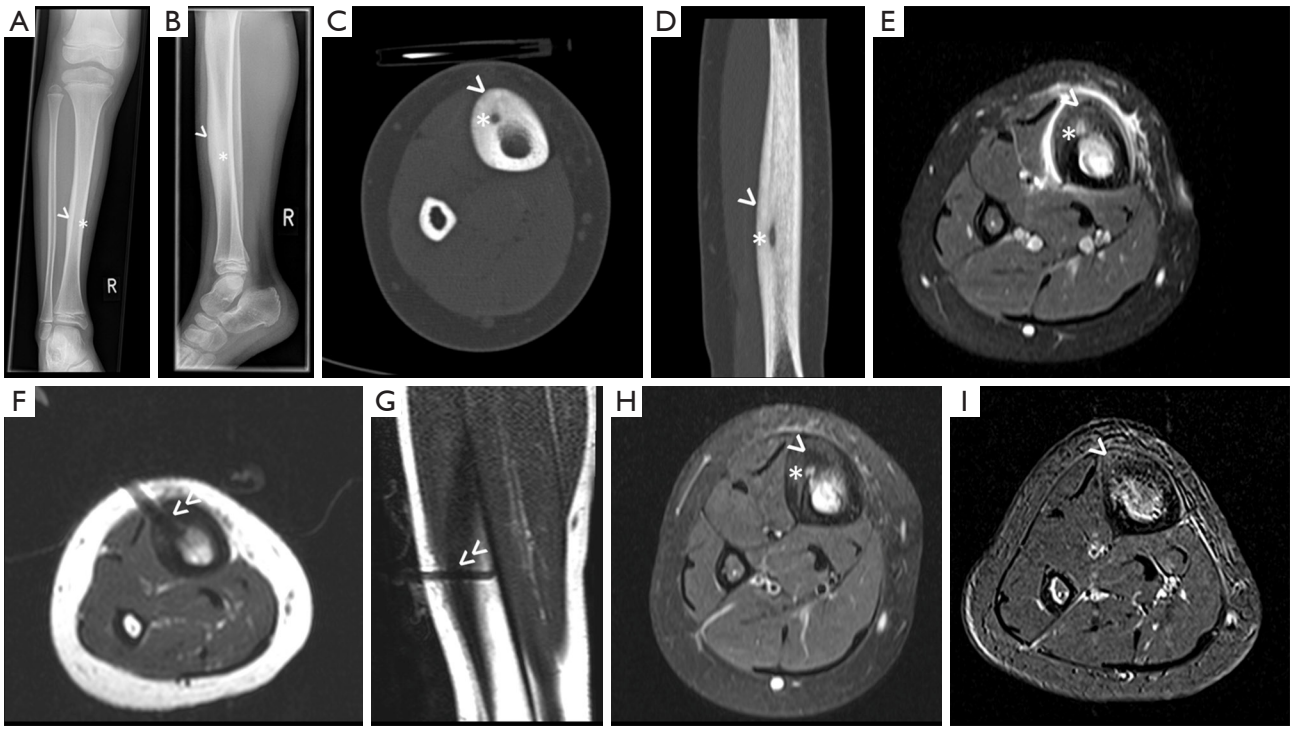


Figure 4 Seven-year-old boy with OO of the right tibial shaft (typical localization) presenting with nocturnal pain. Primary technical and clinical success, no complications. Both conventional X-ray (A,B) and CT scans (C,D) show typical features such as cortical thickening and central nidus. Preprocedural MRI (PDw with fat saturation in axial orientation) (E) visualizes nidus and edema. MRI during intervention with periprocedural verification of instrument placement (PDw TSE in axial (F) and sagittal orientation (G). (H) MRI 3 months after intervention (PDw with fat saturation in axial orientation) showing edema/hematoma in the nidal area; (I) MRI 3 months after intervention (subtraction of contrast-enhanced and native T1w TSE) demonstrating a loss of nidal enhancement, thus proving complete ablation; *, nidus; >>, needle; >, cortical thickening. OO, osteoid osteoma; PDw, proton-density weighted; TSE, turbo spin echo.

clinical failure as well as minor adverse events were most commonly observed in patients treated for atypical OO. This finding is consistent with atypical OOs also being referred to as technically challenging, and may explain the slightly lower primary success rate of 86% in our patient collective with 59% atypical OO. In particular in these cases, MRI thermometry may be useful for sparing adjacent neurovascular structures and thus potentially increasing the efficiency and safety of LA in patients with atypical OO. MRI thermometry thus has the potential to improve overall treatment quality. Regarding success and complication rates, our results are comparable with outcomes reported for CT-guided RFA (12,40-42). Lassalle *et al.*, for example, reported a primary success rate of 94.3% (79/88) and few minor complications (40). Also in line with the results of previous studies, we did not observe any major complications (6,10,14,43).

Atypical OO are also called "technically challenging". One patient with OO of the toe had to be treated with a modified ablation protocol (low temperature, low duration) in order to save structures at risk (here: close to the skin). He suffered recurrence and underwent open surgery, yet secondary treatment using CT-guided RFA would also have been an option in this location. Another patient with recurrent OO in difficult location, in the femoral neck, also underwent successful secondary treatment using CT-guided RFA. Due to the ALARA principle regarding radiation exposure, which is especially important in young patients, MRI guidance should be considered as the primary therapy recommendation if available, reserving CT guidance as secondary alternative when higher spatial resolution may be needed for optimal outcome.

Subjective treatment satisfaction in our patients was very good at both short-term (97%) and long-term (100%)

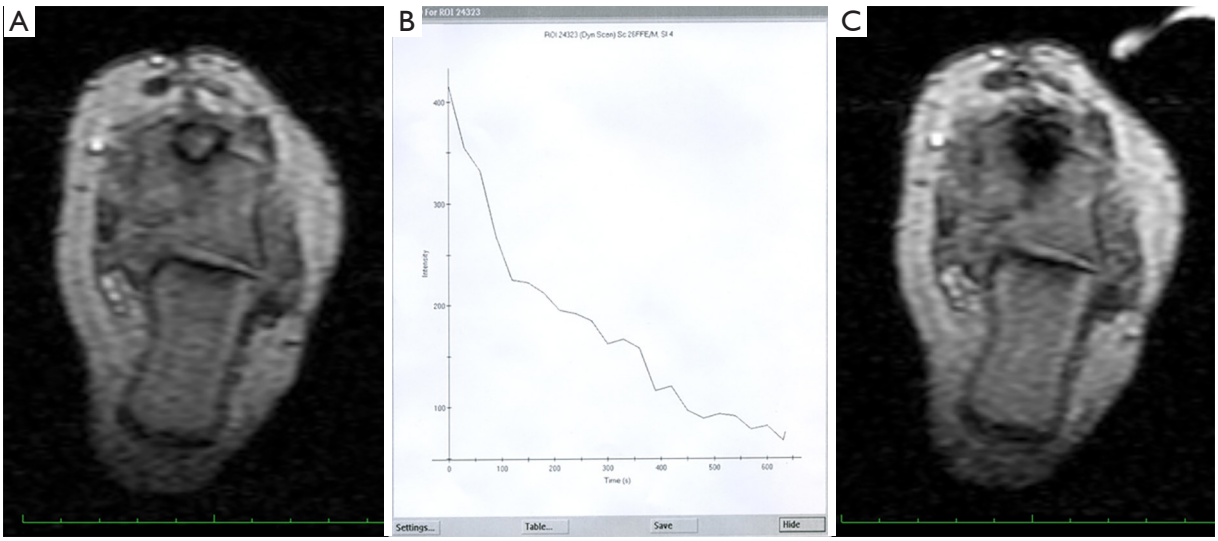
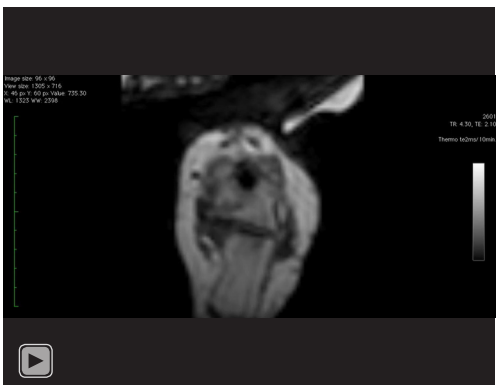


Figure 5 MRI thermometry (T1 relaxation). During the procedure, MRI thermometry was used to spare neurovascular structures in the vicinity (white circle in *Figure 3C*). T1-signal loss in the OO of the right talus in the patient presented in *Figure 3*. Images of MR thermometry (A) at beginning (t=0 s), and (C) at the end of laser ablation (t=600 s) with a clear demarcation of the ablation zone, while sparing neurovascular structures. (B) Graph illustrates decrease of signal intensity over time. See *Video 1*. OO, osteoid osteoma; MR, magnetic resonance.



Video 1 Online MRI thermometry (T1 relaxation) during application of MR guided LA of an OO of the right talus in a 64-year-old female patient as presented in *Figures 3,5*. MR, magnetic resonance; LA, laser ablation; OO, osteoid osteoma.

follow-up. This also resulted in a high willingness to undergo the same procedure again, if necessary. The results in terms of satisfaction are also consistent with reports from previous studies (6,10,41,43).

As limitations, the study focused on MRI-guided LA without direct comparison to CT-guided RFA. Although we conducted a telephone survey instead of a personal clinical examination, still a number of patients was lost to follow-up, resulting in a smaller number of patients available for long-term interviews. As strength of this study we want to underline the long follow-up period of a mean of 116 months. Long-term imaging follow-up was not conducted, which, however, is justified by the absence of clinical symptoms.

Conclusions

In conclusion, MRI-guided LA of OO is a safe and effective technique with high patient satisfaction and acceptance rates in short-term and long-term outcome. MRI thermometry can help interventionalists spare neurovascular structures in the proximity of atypically located OO. Recurrence and minor adverse events were more common in atypically located OO, suggesting that CT should be considered in patients with OO in locations requiring higher local resolution for image guidance.

Acknowledgements

We would like to thank Bettina Herwig for thorough language editing of our manuscript.
Funding: None.

Footnote

Reporting Checklist: The authors have completed the MDAR reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-21-3343/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-21-3343/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-21-3343/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional ethics committee of Charité – University Medicine Berlin (No: EA1/301/12) and individual consent for this retrospective analysis was waived.

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Cite this article as: Seemann R, Böning G, Schwabe P, Teichgräber U, Gebauer B, Streitparth F. Osteoid osteoma: treatment outcome and long-term follow-up after MRI-guided laser ablation. Ann Transl Med 2022;10(5):240. doi: 10.21037/atm-21-3343

