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SCIENTIFIC ARTICLE

Radiofrequency ablation vs microwave ablation for osteoid osteomas: long-term results

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Abstract

Objective Osteoid osteomas are benign bone tumors commonly treated using thermal ablation. We compare the technical success, complication rates, and long-term efficacy of the two most common ablation types: radiofrequency and microwave.

Materials and methods A retrospective study was performed of all osteoid osteoma ablation procedures between 2007 and 2017. A ten-point numerical pain scale was used to quantify symptoms before and after the procedures with > 12-month follow-up. Complications were reported using the Society of Interventional Radiology Adverse Events reporting criteria.

Results Twenty-nine patients successfully underwent 15 radiofrequency ablations and 15 microwave ablations with a technical success rate of 83% for radiofrequency and 100% for microwave ($p = 0.23$). Long-term recurrence rates ($p = 1.0$) and complication rates ($p = 0.60$) were not significantly different for the groups. One patient developed a skin burn following microwave ablation and another developed 12 months of sciatic neuropathy following radiofrequency ablation.

Conclusion Microwave and radiofrequency ablation are safe and effective methods for treating osteoid osteomas with similar long-term efficacies. Although radiofrequency ablation is more commonly reported to result in skin burns, this complication can arise during microwave ablation.

Keywords Ablation · Osteoid osteoma · Microwave · Radiofrequency · Radiology

Introduction

Osteoid osteomas are benign bone tumors composed of a dense trabeculated nidus surrounded by vascular connective tissue containing unmyelinated nerves and surrounding reactive bone [1]. They commonly present with focal pain directly over the tumor that is worse at night or with activity. Traditional treatment methods include conservative medical therapy and en bloc surgical resection. Minimally invasive therapy with radiofrequency ablation (RFA) was first reported in 1992 and has since become a primary method of treatment [2]. Additional ablative techniques using microwave ablation (MWA), cryoablation, alcohol ablation, laser ablation, and high-intensity focused ultrasound (HIFU) have since been described [3]. While RFA continues to be the most common method of ablation, an increasing number of studies have reported similar technical success and complication rates with microwave ablation [4]. However, long-term recurrence has not been compared between the two modalities. We compare the technical success, complication, and long-term (> 12 months) clinical success rates of MWA to impedance-based RFA in a limited cohort of patients.

Methods

A retrospective electronic chart review was performed of all patients referred to the Interventional Radiology Department for ablation treatment of an osteoid osteoma between 2007 and 2017 following Institutional Review Board approval. Exclusion criteria included patients who received biopsy only, patients who underwent a separate type of thermal ablation from MWA or RFA such as cryoablation, patients with other bone tumors, and patients lost to long-term follow-up (>

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12 months) following treatment. Pre-procedure workup included clinical history and physical examination, radiologic imaging, and a coagulation panel. All patients underwent a ten-point numerical pain scale assessment of their average symptom level prior to ablation.

Informed consent was obtained prior to each procedure. The anesthesia team subsequently evaluated each patient before undergoing sedation. Imaging guidance during the procedure was performed utilizing CT fluoroscopy (Philips Healthcare, Andover, MD). The CT protocol included a planning CT scan with grid marker at 2-mm slice thickness followed by CT fluoroscopy at 2.75- to 5-mm slice thickness.

Biopsy was performed prior to ablation in all cases. Bone biopsy needles were selected based on availability and provider preference, including Bonopty (AprioMed, Inc., Derry, NH), Jamshidi (BD, Franklin Lakes, NJ), Laurane (LauraneMedical, Westbrook, CT), OnControl (Teleflex, Morrisville, NC), Osteo-Site (Cook Medical, Bloomington, IN), and Ostycut (Bard, Tempe, AZ) needles. Ablation probes were then inserted through coaxial biopsy sheaths when possible (Fig. 1).

Ablations were initially performed using RFA until a MWA system was purchased. Radiofrequency ablation was performed using a Soloist probe (RF 3000 generator, Boston Scientific, Natick, MA) or a Starburst XL probe (RITA 1500XL generator, Angiodynamics, Queensbury, NY). Grounding pads were applied before the procedure to a hair-free surface on the skin away from the entry site. Following placement of the RF probe through a coaxial sheath into the osteoid osteoma, the sheath was retracted as far as possible from the probe tip. The treatment protocol for the RF3000 system was an initial power of 2 W followed by incremental 1-W increases every minute until roll-off—the rapid rise in impedance or resistance of the alternating current dispersed through the ablation probe due to desiccation or necrosis of surrounding tissues which signifies completion of the ablation procedure [5]. Two heating cycles were performed at 1-min intervals. Treatment times per cycle ranged from 1.5 to 7 min. RITA 1500XL ablations were performed with a set target temperature of 100 °C and heating cycles ranging from 5 to 6 min at 1-min intervals.

All MWA patients were treated using a PR 15 Probe (NuWave Generator, Nuwave Medical, Madison, WI). Following placement of the microwave probe through a coaxial sheath into the osteoid osteoma, the sheath was similarly retracted as far as possible from the probe tip. Three cycles of ablation were performed at 30 to 50 W for 30 s with continuous temperature monitoring at 1-min intervals targeted to a minimum of 80 °C. For one large OO that was 2 cm in craniocaudal length, the ablation probe was repositioned after its first cycle to a different craniocaudal location and ablation was repeated.

Post-procedure CT imaging was performed as above, hemostasis was achieved with manual compression, and the site was inspected for skin burns prior to the application of sterile dressing. Grounding pad sites were likewise inspected for skin burns during removal. Patients were sent to a recovery area for a minimum of 1 h prior to being discharged. All patients were discharged with crutches to be used until their follow-up appointment with the referring orthopedic surgeon in 7–10 days and were permitted to return to high-impact sports 4–12 weeks after the procedure.

A ten-point numerical scale of the patient's average pain level following ablation was utilized during follow-up at 1 month and at 3–6 months. Assessment for recurrence of symptoms or delayed complications was also performed after a minimum of 12 months using either a phone-based questionnaire with consent or through electronic chart review which employed the same ten-point numerical pain scale.

Technical success was defined as the completion of RFA or MWA using the protocols detailed above. Clinical success was defined as resolution or near resolution of symptoms based on the ten-point numerical pain scale immediately

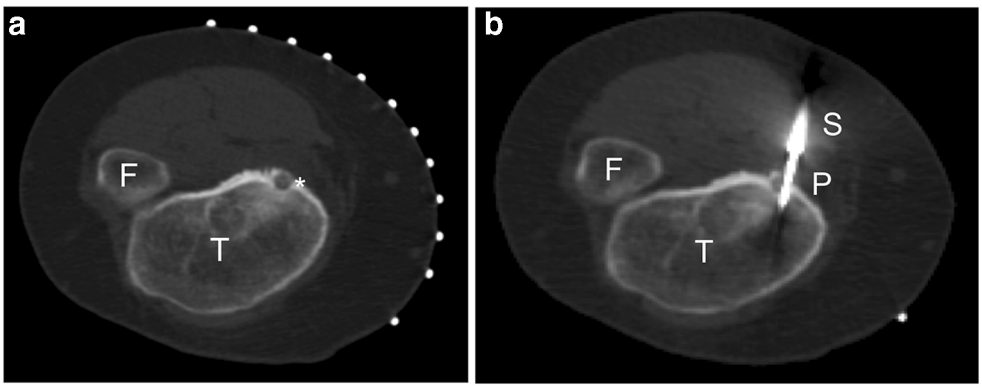

Fig. 1 **a** 23-year-old girl presenting with an osteoid osteoma (*) of the tibia (T) depicted on this axial planning CT scan. F fibula. **b** 23-year-old girl presenting with an osteoid osteoma of the tibia. Axial CT image demonstrating an ablation probe (P) inserted through a coaxial osteosite biopsy sheath (S) into the medial aspect of the osteoid osteoma prior to sheath retraction. T tibia, F fibula

following treatment (< 4 months) and after long-term follow-up (> 12 months).

Demographic, clinical, and procedural data were compared between the RFA and MWA groups. A Student's *t* test was used to compare the continuous variables age, duration of symptoms, duration of follow-up, and nidus characteristics. Proportions including sex, OO location, and technical success were compared using a Fisher's exact test. The remaining pre- and post-procedure pain scales were compared with a Mann-Whitney *U* Test.

Results

A total of 42 patients were treated for osteoid osteomas. Patients who received enucleation biopsy alone ($n = 9$) or biopsy after failed RFA ($n = 1$), patients lost to follow-up ($n = 2$), and a patient with a concomitant osteosarcoma ($n = 1$) were excluded. The remaining 29 individuals successfully underwent a total of 15 RFA procedures and 15 MWA procedures.

The average age of RFA patients was 17.4 years (range 7.8–36.1) and 17.6 years (range 8.6–47.9) for MWA patients as shown in Table 1. Although the oldest MWA patient presented outside of the expected age range, her presentation suggested an OO and biopsy performed during the ablation was pathologically consistent with an OO.

Pre-procedure imaging included MR, CT, radiographs, and bone scans when appropriate (Table 1). The average time from confirmatory imaging to treatment was 2.3 months (range 0.1–14.2) for RFA and 3.0 months (range 0.4–12.2) for MWA ($p = 0.62$). Both MR and CT were obtained in 4

Table 1 Patient demographics

	Radiofrequency	Microwave	*p* value
Age (years) [range]	17.4 [7.8–36.1]	17.6 [8.6–47.9]	0.96
Sex (M:F)	12:3	8:7	0.25
Symptoms			
Duration (months) [range]	8.8 [3.0–24]	5.9 [1.0–12.6]	0.15
Night pain	94%	93%	
NSAID use	100%	78%	
Location			0.50
Radius			
Head	–	1	
Pelvis			
Ischium	1	–	
Femur			
Femoral neck	1	2	
Lesser trochanter	1	–	
Metaphysis	2	4	
Diaphysis	5	2	
Tibia			
Metaphysis	–	3	
Diaphysis	5	–	
Fibula			
Diaphysis	–	2	
Talus			
Posterior facet	–	1	
Pre-procedure imaging			
MR and CT	4	9	
MR alone	3	4	
CT alone	4	2	
Other	4	–	
Nidus			
Maximum length (cm) [range]	1.1 [0.7–1.7]	1 [0.5–1.9]	0.65
Eccentricity ratio [range]	2 [1.1–3.3]	2.4 [0.8–4.8]	0.18

RFA and 9 MWA patients when the initial MR study was non-confirmatory. Bone scans were performed in 3 patients whose diagnosis remained uncertain following MR and 1 patient underwent treatment following a confirmatory femoral radiograph.

Technical success was 100% for microwave and 83% for radiofrequency ablation (Table 2). Radiofrequency ablation could not be performed due to error message E02—high initial impedance—in the failed cases and did not respond to restarting the system. Ablation was subsequently performed with MWA through the same access intra-procedure in 2 cases included in the MWA cohort. The third patient was treated with cryoablation 3 months later and excluded from the remainder of the study analysis.

Recurrence necessitating treatment occurred after 25 months in 1 MWA patient and 22 months in 1 RFA patient. The MWA recurrence was treated surgically and RFA recurrence was treated with MWA—the latter patient was included in both the RFA and MWA cohorts. Two additional patients reported mild symptoms (2–4 out of 10 intermittent pain every 4–6 months) that they felt was much improved and did not necessitate retreatment.

One major complication occurred in the MWA group in the patient retreated following RFA recurrence. The patient suffered a second-degree skin burn at the access site and subsequent cellulitis requiring hospitalization for IV antibiotics. He initially presented 1 month after treatment with skin breakdown, serosanguinous drainage, increasing erythema, and tenderness over the wound. Sterile dressing was maintained over the site and the presumed infection initially responded to cephalexin. Unfortunately, the site became re-infected 1 month later with gram-negative organisms and required treatment with IV clindamycin followed by oral ceftriaxone at an outside facility. Healing occurred after 6 months leaving a 5-mm scar. One minor complication occurred in a patient who suffered numbness over the treatment site for 3 months that self-resolved. Another patient experienced mild forearm, wrist, and hand-grip weakness following treatment of a distal humeral osteoid osteoma; however, this was felt to be caused by prolonged disuse prior to ablation.

No major complications occurred in the RFA group. One minor complication of sciatic nerve irritation occurred following treatment of an ischial OO that initially required a leg brace followed by 12 months of physical therapy with resolution of symptoms.

Discussion

This study focused on the technical success, clinical success, and complication rates of RFA compared with MWA. The clinical success rates of RFA and MWA in this study were similar to respective rates of 79 to 100% and 92 to 100% in the literature [4, 6–13]. Our results are notable for the length of procedural follow-up and presence of RFA technical issues.

Pain symptoms were the primary indication for referral of OO treatment by our orthopedics group and long-term success was defined as the resolution of pain-related symptoms from the osteoid osteoma. Only one OO in this study was periarticular. Peri- and intra-articular osteoid osteomas may require treatment despite a lesser degree of symptoms to prevent chronic synovitis, osteoarthritis, and joint contracture [14]. Successful treatment with percutaneous ablation has been reported at > 90% with a low rate of complications [15, 16].

Previous literature has suggested that success and complication rates of MWA are comparable with RFA; however, there are few reports of clinical success beyond 6 months [4, 13]. Recurrence of osteoid osteomas ranges from 10 to 16% [17–21]. Long-term RFA follow-up suggests an OO recurrence rate of 7.5%, which underscores the importance of diligent monitoring for approximately 2 years following treatment [20, 22]. Recurrences have been correlated with female sex, maximum dimension of the nidus and clear zone, and eccentricity ratio of the longest to shortest nidus dimensions [20, 21]. Our study data, although limited in size, suggest a

Table 2 Success rates and complications

	RF	Microwave	*p* value
Technical success	83%	100%	0.23
Pre-procedure pain score [range]	8 [5–10]	7 [3–10]	0.23
Immediate post-procedure pain score (< 4 months) [range]	0.2 [0–2]	0 [0]	0.77
Long-term post-procedure pain score [range]	0.8 [0–10]	0.4 [0–6]	0.77
Follow-up duration (months) [range]	53.7 [15.3–133.1]	33.8 [14.7–57.4]	0.039
Recurrences	1	1	1.0
Complications	1	3	0.60
Major	0	1	
Minor	1	2	

comparable rate of long-term recurrence following RFA and MWA.

We did encounter technical failures with the RF3000 generator despite replacement of the Soloist probe, repositioning of the needle, small-volume (< 0.1 mL) sterile saline infusion through the coaxial needle, and rebooting of the system. The generator E02 error message signified high initial impedance prior to the start of the ablation cycles. Each of these technical failures was reported to the manufacturer and no testable generator malfunction was identified between cases. While this message may have been caused a lack of conduction within bone from a persistent air block (despite fluid being instilled into the ablation site), generator malfunction was suspected and eventually contributed to our microwave ablation transition [23]. There have been similar reports of RF3000 generator failure with the same error message on the MAUDE adverse events reporting log, but impedance-based RFA of osteoid osteomas does have a high technical success rate in the literature [24]. Therefore, this was considered an equipment issue rather than an inherent disadvantage of RFA compared with MWA.

RFA and MWA treat OO symptoms by heating and irreversibly damaging unmyelinated nerve fibers. The mechanism of each ablation modality is different with relative advantages and disadvantages. RFA generates heat by the conduction of high-frequency alternating current through a closed circuit that requires grounding pads to be placed on the patient. Ablation coverage is limited and probes cannot conduct through charred or desiccated tissue, but the ablation size is well controlled and can be spherical [25]. Conversely MWA heats tissues through the vibration of polar molecules (water) as they attempt to align in an alternating electromagnetic field [26]. The system does not require grounding pads and conducts heat independent of charring, but typically heats in an ellipsoid fashion rather than spherical potentially burning non-target tissue including overlying skin [27, 28]. The development of electrode cooling systems and use of short, low-power heating protocols for OOs has decreased the likelihood of this occurrence [26].

One skin burn occurred in our study during the repeat MWA of an RF-ablated lesion. The wound became infected requiring both oral and IV antibiotics, but eventually healed. The rate of complications in the literature is variable ranging from 1 to 24%, including skin burns, necrosis, osteomyelitis, soft tissue infection, complex regional pain syndrome, neuropathy, tendonitis, and hematoma [29, 30]. These complications should be considered in the context of lesion location; proximity to the skin, joints, neurovascular bundles and myotendinous junctions; percutaneous approach; and the RFA protocol. Location of osteoid osteomas in significant weight-bearing areas such as the proximal femur may require an approach that avoids areas of the bone that predominantly support tensile forces, as discussed by Witmore et al. [31]. The skin burn in this case may have been related to the proximity of the tibia to the overlying dermis and the presence of a previous ablation tract that was used for percutaneous access in both procedures. While both modalities risk skin burns at the ablation site, RFA continues to risk burns at the grounding pad sites as well [32]. Recent studies of microwave ablation have suggested a similar risk of ablation site skin burns [10].

Limitations of the study include the small sample size, single-center inclusion, variability in biopsy and ablation techniques, and lack of treated OOs in the spine or peri-articular region. As more MWA studies are performed with greater sample sizes and longer follow-up, the success and complication rates may adjust closer to those of radiofrequency ablation. MWA will continue to have the advantage of no grounding pad burns.

Despite the technical issues we encountered with RFA, both ablation modalities have high success rates and a similar complication profile.

Compliance with ethical standards

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

Ethical statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (University of Rochester Research Subjects Review Board) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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