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INTERVENTIONAL

Radiofrequency ablation for non-spinal osteoid osteomas in 557 patients

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Abstract
Objectives To present the results of biopsy and computed tomography (CT) guided radiofrequency ablation (RFA) for non-spinal osteoid osteomas, and compare the results before and after procedural modifications.
Methods We retrospectively studied 557 patients with non-spinal osteoid osteomas treated with biopsy and CT-guided RFA. In 68 patients we used 3-mm CT at 2-mm intervals, 19 G/5-mm active tip electrodes, and one 4-minute ablation at 90–93°C. In 489 patients we used contiguous 1-mm CT, 20 G/5-15-mm electrodes, ablation maintaining 60°C for 2 min followed by 14–15 min at 90–93°C, and multiple ablations in the same session for large and multiform lesions.
Results 533/557 patients (96%) remained asymptomatic and 24/557 (4%) had recurrence; repeat RFA was successful in 22/24 patients (92%). Biopsy was non-diagnostic in 82%. With the modifications performed, success improved from 79% to 98%, recurrences reduced from 21% to 2% and complications from 5.9% to 0.2% ($p< 0.001$). All patients with large and multiform lesions treated with one ablation had recurrence, compared to no patient with similar lesions and multiple ablations in the same session.
Conclusion Electrode parameters, duration of ablation, morphology and size of osteoid osteomas are important for RFA. The above modifications are recommended for improved outcome.
Key Points
• *Most osteoid osteomas can be reliably diagnosed by imaging.*
• *Biopsy yields reliable results in less than 50% of cases.*
• *Radiofrequency ablation (RFA) is safe and effective for osteoid osteomas.*
• *RFA is a minimally invasive outpatient treatment.*
• *Small caliber (20 G/0.9 mm) active tip electrodes and 14–15-minute ablation at 90–93°C is recommended.*

Keywords Osteoid osteoma · Radiofrequency ablation · CT-guided · Biopsy · Recurrence

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Introduction

Osteoid osteomas are benign bone tumors with a <20 mm oval or round radiolucent nidus surrounded by uniform

reactive sclerosis [1]. Most lesions are extraarticular; approximately 13% are intraarticular [1–3], most commonly involving the hip joint with atypical symptoms related to synovitis [1–5]. Initial treatment for osteoid osteomas consisted of prolonged anti-inflammatory treatment for 30–40 months [6, 7], and en bloc excision of the nidus if histology is in doubt, neurovascular structures are within 15 mm, and percutaneous techniques have failed [6–9]. However, recurrence may occur after cessation of anti-inflammatory treatment [7], and persistent or recurrent symptoms from incomplete excision of the nidus, prolonged hospitalization, need for internal fixation and bone grafting, joint stiffness, avascular necrosis, and postoperative fractures have been associated with surgery [6, 8].

Several percutaneous minimally invasive techniques have been used for destruction of the nidus of osteoid osteomas such as trephine, laser and radiofrequency ablation [6, 8, 10–17]. Radiofrequency ablation (RFA) is a form of electrosurgery in which an alternating current of high-frequency radiowaves (>10 kHz) flows from a radiofrequency (RF) generator through an electrode tip and dissipates its energy as heat [18]. Tissue resistance causes local ions to vibrate in direction of the alternating current and create heat to the point of dessication. In contrast to electrocautery, the primary source of heat is the tissue around the active tip of the electrode, and the maximum volume of ablation is the area around the active tip [18, 19]. Effective ablation in living bone has been achieved with 90°C at the active tip for 4–6 min [6, 8, 12, 15, 16, 20]. The RFA time depends on the calibre and the length of the active tip, the temperature applied, and the location, morphology and size of the lesions [21, 22]. The maximum effective calibre of the active tip is 2 mm [21, 22]. Because of the relatively small size of osteoid osteomas, and the predictable zone of thermal necrosis, loss and weakening of bone is minimal [14, 15].

We performed this study is to present the results of biopsy and CT-guided RFA for non-spinal osteoid osteomas, and to compare the results before and after procedural modifications performed over time.

Materials and methods

Patients

We retrospectively studied the files of 557 patients with non-spinal osteoid osteomas who underwent primary treatment with CT-guided RFA at our institution from March 1999 to January 2010. There were 364 male and 193 female patients, with a mean age of 21 years (2–68 years). The most common location was the long bones (Fig. 1). Sixty-five tumors (12%) were intraarticular and 492 extraarticular (Table 1). All patients were taking analgesics including anti-inflammatory drugs on almost a daily basis; 307 patients (55%) had pain for <6 months and 250 (45%) for >6 months. Patients with extraarticular tumors experienced typical symptoms, and those with intraarticular experienced atypical pain and painful motion of the involved joint. The mean follow-up was 3.5 years (0.5–9 years); no patient was lost to follow-up. This study was approved by the Institutional Review Board/Ethics Committee of the authors' institution.

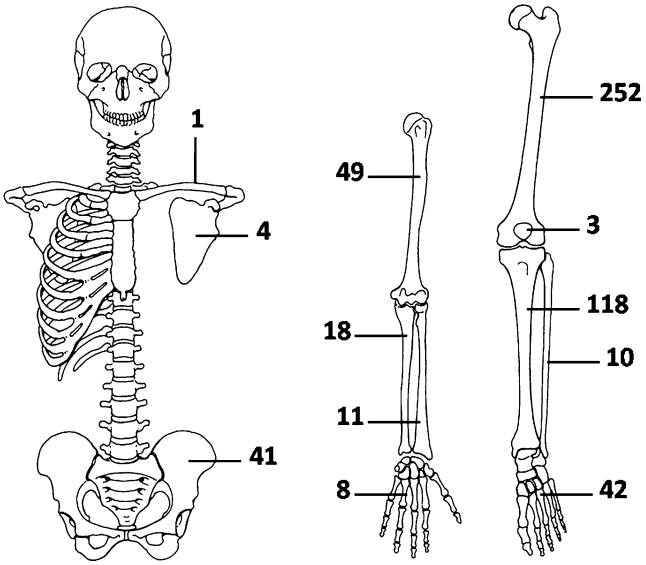

Fig. 1 Location of the osteoid osteomas

Table 1 Location of the intraarticular and extraarticular osteoid osteomas

Intraarticular osteoid osteomas		
Joint		
Hip	Femoral head and neck	21
	Acetabulum	7
Knee	Patella	3
	Tibial condyles	3
Foot	Talus	17
	Cuneiforms and metatarsals	6
Shoulder	Humeral head	4
	Glenoid	1
Elbow	Olecranon	1
Hand	Carpus	2
Total/*n*=65 (12%)		
Extraarticular osteoid osteomas		
Cortical		320
Cancellous		172
Total/*n*=492 (88%)		

Imaging and RFA procedure

The indications for RFA were the typical clinical and imaging findings of osteoid osteomas. The most common appearance was oval lesions surrounded by periosteal and endosteal sclerosis (432 lesions, 77.5%), followed by round (95 lesions, 17%) and multiform (30 lesions, 5.5%). Multiform were non-spherical lesions such as nephroid, bilobular, serpiginous or with irregular rim. The mean size of typical lesions was 9.5 mm (4.5–10 mm); the mean maximum diameter of multiform lesions was 12 mm (10–20 mm).

All patients were treated by the same operators with similar experience levels after being informed about the procedure, the benefits and possible complications of RFA. Spinal or epidural anaesthesia was administered in 309 patients; general anaesthesia in 128 young patients and patients with upper extremity lesions; local anaesthesia (2–5 ml mepivacaine cloridate 2%) and peripheral nerve blockade in 101 patients; and only local anaesthesia and infiltration of the periosteum in 18 patients with subperiosteal tumors. Next, CT without contrast media was performed to localize the lesion and plan the approach to avoid vital structures. We preferred a perpendicular approach with the patient supine, and avoided a transarticular approach. After choosing the insertion point on multiplanar reconstructions, the position was ascertained by CT using a radiopaque landmark and the skin was marked. A stab incision was made and a biopsy trochar (Bone Biopsy System, Bonopty, Radi Medical Device, Sweden) was advanced to cortex. In cases with dense cortical bone, drilling through the cortex (Bonopty drill set, standard length 122 mm, extended length 160 mm, calibre 15 G12/1.7-mm) was performed. After reaching the nidus, in all patients tissue sample was obtained for histology using a biopsy needle (Bonopty biopsy needle, Radi Medical Device, Sweden) inserted through the trochar. Next, the electrode was inserted through the trochar aiming at the center of the nidus of its active tip under CT-guidance. We first connected the grounding pads and then the electrode to the RF-generator (RFG-3 C Radionics, Tyco Healthcare Group LP, Burlington, Mass, USA). Before supplying the RF waves, care was taken that the active tip was not in contact with the trochar to avoid soft tissue burn, and the distance of the active tip was >15 mm from neurovascular structures and >10 mm from skin when delivering high energy. Low energy was delivered for superficial lesions, and lesions in the bones of the hands and feet.

Ablation was performed at 90–93°C [6, 8, 12, 15, 16, 20]. Ablation time varied according to the calibre and length of the electrode's active tip, and the location, morphology and size of the lesions [21, 22]. We were choosing the electrode's active tip length according to nidus maximum diameter; 5-mm active tip was used for nidus <10 mm (56 patients), 10-mm active tip for nidus 10–15 mm (473 patients), and 15-mm active tip for nidus >15 mm (28 patients). Multiple ablations in the same RFA session were performed for complete thermal destruction of osteoid osteomas with nidus diameter >15 mm and multiform osteomas when the distance between the active tip of the electrode and the wall of the nidus was >8 mm. The electrode was cooled with normal saline. After ablation, the electrode and trochar were removed, and the wound was closed with a sterile strip.

Overall, 622 ablations were performed; 520 patients had one ablation, 37 patients with osteoid osteomas with nidus diameter >15 mm and multiform osteomas had two (33 patients) or three (four patients) ablations at the same RFA session, and 24 patients with recurrent pain had repeat RFA. After the procedure, all patients were examined for bleeding, swelling and burns, and inquired about pain. The patients were admitted the day of the procedure and discharged the next day with instructions for unrestricted weight-bearing and avoiding sports for 3 months. Clinical follow-up examination was performed at 1, 3, 6 and 12 months after RFA; CT and/or magnetic resonance imaging was performed in patients with persistent or recurrent symptoms.

Modifications to RFA procedure

We evaluated our results with RFA into two time periods: before September 2002 in which 68 patients were treated, and after September 2002 in which 489 patients were treated (Table 2).

In the first study period, local infiltration of the periosteum was performed only in two patients with subperiosteal tumors. CT-guidance was performed using 3-mm slice CT at 2-mm intervals, technical parameters 120 kV, milliamperage depending on the location of osteomas (limbs, 150 mA; pelvis, 300 mA), and bone algorithm; a final CT data acquisition was performed from proximal to distal end of the lesions for multiplanar reconstructions. In 14 patients at the beginning of the first study period, we used the RA-TC electrode (calibre 19 G/1 mm, active tip 5-mm). Thereafter until currently we used the SMK-TC electrode (calibre 20 G/0.9 mm, active tip 5–15-mm). One ablation was performed for 4 min by raising the temperature directly to 90–93°C.

In the second study period, local infiltration of the periosteum was performed in all patients for post-procedural analgesia. CT-guidance was performed using contiguous 1-mm slice CT, and the same technical parameters; the final CT data acquisition for multiplanar reconstructions was performed 5 mm proximally and distally to the lesion. During trochar and electrode insertion, the milliamperage was halved to reduce the radiation dose to the patient. In all patients the SMK-TC

Table 2 Modifications, successes and failures

Study period	Patients	Infiltration of periosteum	CT-guidance[a]	Electrodes	Temperature and time of ablation	Successes	Recurrences	Complications
March 1999–August 2002	68	5–10 ml of 2 mg/ml solution of ropivacaine hydrochloride (two patients)	3-mm slice thick CT slices at 2-mm intervals	RA-TC electrode (active tip 5-mm)[b] (14 patients) SMK-TC electrode (active tip 5–15 mm)[c] (54 patients)	Direct raising to 90–93°C and ablation for 4 min	54/68 (79%)	15/68 (28%)	4/68 (6%)
September 2002–January 2010	489	5–10 ml of 2 mg/ml solution of ropivacaine hydrochloride (all patients)	Contiguous 1-mm slice thickness CT. During trocar and electrode insertion, the milliamperage was halved to reduce the dose of radiation to the patient	SMK-TC electrode (active tip 5-15-mm)[c] (all patients)	Maintaining 60°C for 2 min and then ablation at 90–93°C for 14–15 min	479/489 (98%)	9/489 (2%)	1/489 (0.2%)
p-value						<0.001	<0.001	<0.001
Total/n(%)	557					533/557 (96%)	24/557 (4%)	5/557 (1%)

[a] technical parameters were the same between the two study groups: 120 kV, milliamperage depending on the location of the lesion (150 mA for the limbs and 300 mA for the pelvis), bone algorithm, and multiplanar reconstructions

[b] RA-TC electrode (length 220 mm, calibre 19 G/1 mm, active tip 5-mm); Radionics, Burlington, MA, USA

[c] SMK-TC electrode (length 145 mm, calibre 20 G/0.9 mm, active tip 5–15-mm); Cotop International, Amsterdam, The Netherlands

electrode and two self-adhesive grounding pads (11× 17 cm) applied to the skin symmetrically to the lesion were used. Ablation was performed at the same temperature (90–93°C), but although this has been proven to be effective only in soft tissue ablation [21–25], since we changed to smaller calibre active tip electrodes (20 G/ 0.9 mm) we increased the time of ablation to 14–15 min to obtain complete tissue burn of the same tissue volume. Moreover, we performed repeat ablation at the same RFA session for osteoid osteomas with nidus diameter >15 mm and multiform osteomas. Obtaining experience, we observed that cortical osteoid osteomas and osteomas with large sclerotic rim have high tissue impedance (TI). The RF generator senses TI and delivers the optimum amount of energy; low TI permits maximum energy deposition for a larger effective ablation volume. When TI was $\geq 1\,\Omega$, by raising directly to 90–93°C the RF generator automatically turned-off. By gradual raising the temperature and maintaining 60°C for 2 min, TI and RF output were reduced. Initially in the second study period from September 2002 to January 2007, we maintained 60°C for 2 min for cortical osteoid osteomas and osteomas with large sclerotic rim regardless of their size, because these lesions had higher TI. Thereafter until currently, we use this ablation plan for all osteomas because we consider more effective for reduction of TI, improved RF-generator output, and cooling the electrode.

Statistical methods

This study was a retrospective clinical study. The observation period was 12 months, followed by another 12 months for patients with recurrences. Successes (pain relief) and failures (recurrences and complications) were analyzed before and after the modifications performed (Table 2). Statistical analysis was done using the chi-square test; significance was set at $p < 0.05$. Biopsy was performed in the same way in both study periods and was not included in the statistical analysis.

Results

All patients experienced post-procedural pain reduction; 445 patients (80%) experienced pain relief the next day, 72 (13%) within the next 2–3 days, and 40 (7%) within the first week after RFA. Eighty-seven patients experienced for a few days mild discomfort at the site of RFA; 41 of these had intraarticular osteoid osteomas. At the latest follow-up, 533 patients (96%) remained asymptomatic (Fig. 2); 24 patients (4%) experienced pain recurrence at a mean of 6 months (1–15 months); there were 10 male (mean age, 24 years; range, 13–44 years) and 14 female patients (mean age, 26 years; range, 3–47 years); 12 patients with

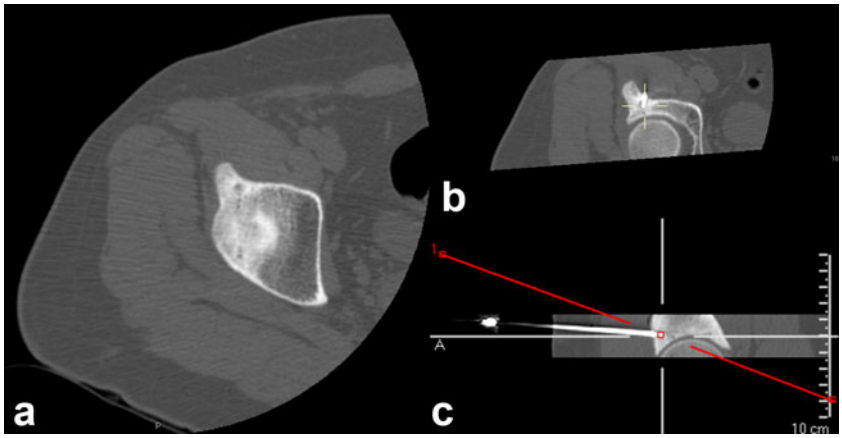

Fig. 2 A 41-year-old man with a 2-month history of intense, persistent pain at the right hip joint. **a** Axial CT shows a round radiolucent lesion with peripheral sclerosis suggesting of osteoid osteoma. **b** and **c** Multiplanar CT reconstructions during RFA for 14–15 min using a SMK-TC 10-mm electrode

recurrence were above age 20 years. All patients with recurrence underwent a second RFA that was successful in 22 (92%) (Fig. 3). The remaining two patients had persistent symptoms and were treated surgically. Imaging follow-up showed variable ossification and bone regeneration at the site of the lesion in all patients with primary or repeat successful RFA.

Biopsy showed osteoid osteoma in 95 patients (17%). In 454 patients (82%) biopsy showed dense, sclerotic, fragmented or normal bone. In eight patients (1%) biopsy showed intraosseous lipoma, bone island, bone infarct, giant cell reparative granuloma, degenerative cyst, fibroma, chondroblastoma and Brodie abscess.

Five patients (1%) had complications. One patient with a proximal tibial metaphysis osteoid osteoma developed thrombophlebitis, and another patient a skin burn. In a patient with a femoral diaphysis osteoma the SMK-TC 15-mm electrode broke. In two patients with femoral diaphysis osteomas the RF generator turned-off repeatedly during the procedure, and the maximum temperature was never reached. Both patients experienced recurrence and were treated successfully with repeat RFA.

With the modifications performed during the second study period, successes statistically significantly improved from 79% to 98%, recurrences reduced from 28% to 2%, and complications reduced from 6% to 0.2% ($p < 0.001$) (Table 2). All patients with osteoid osteomas with nidus diameter >15 mm (four patients) and multiform osteomas (five patients) treated with one RFA during the first study period experienced recurrence, compared to no patient with similar lesions treated with multiple ablations at the same RFA session during the second study period ($p < 0.001$). No patient with repeat ablation at the same RFA session had complications. Although we did not measure the pain that patients experienced during or after RFA, we can conclude that periosteum infiltration was beneficial or at least not harmful for post-procedural pain; all 18 patients with subperiosteal tumors in which only local anaesthesia and periosteum infiltration were performed tolerated the procedure well, without the need for intraprocedural general or spinal anaesthesia.

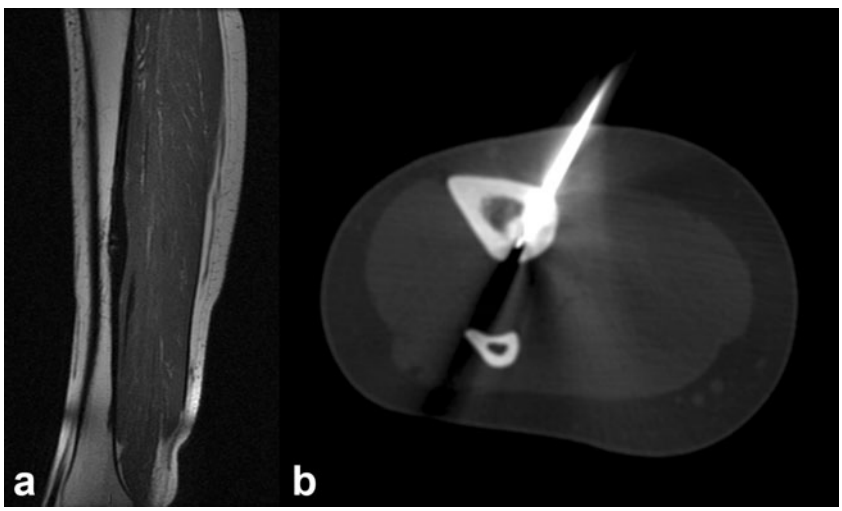

Fig. 3 A 22-year-old woman with recurrent pain and swelling at the left tibia, 12 months after RFA for osteoid osteoma. **a** Sagittal T1-weighted MRI shows intense periosteal reaction with central hyperintensity suggesting of recurrence. **b** Repeat CT-guided RFA for 14–15 min using an SMK-TC 15-mm electrode was succesful

Discussion

Radiofrequency ablation has emerged as safe and effective treatment for osteoid osteomas [6, 8, 13–15, 26]. In this study, we presented the largest long-term series with CT-guided RFA for non-spinal osteoid osteomas, aiming to present the results of biopsy and RFA for these tumors, and to compare the results before and after procedural modifications performed over time. Our results showed that RFA is a successful and safe minimally invasive technique, if performed properly. By using contiguous 1-mm slice CT-guidance, multiplanar reconstructions, 20 G/0.9 mm active tip electrodes, maintaining 60°C for 2 min and then increasing to 90–93°C for 14–15-minute ablation, and performing multiple ablations at the same RFA session for osteoid osteomas with nidus >15 mm and multiform osteomas, successes increased and recurrences and complications reduced significantly. Biopsy was diagnostic in 17%. Although we did not measure the pain that patients experienced during or after RFA, we can conclude that periosteum infiltration was beneficial or at least not harmful for post-procedural pain.

Initial attempts were using 4-minute ablation for osteoid osteomas; however, recurrence rates were high, and most authors prefer 6-minute ablation at 90°C [6, 8, 13, 15, 18, 27]. At the beginning, we were also using 4-minute ablation at 90–93°C; however, most recurrences occurred with this plan. Over time we changed to smaller calibre (20 G/0.9 mm) active tip electrodes and increased to 14–15-minute ablation aiming for complete tissue burn of the same tissue volume [21, 23–25]. In addition, we were gradually raising the temperature maintaining 60°C for 2 min to reduce TI and improve RF output, and then proceeded to 14–15-minute ablation at 90–93°C; by using this ablation plan, successes increased, and recurrences and complications reduced significantly. Although it has been proven only for soft tissue RFA [21–25], when the electrode is inserted into the tissue, the emitted electric current agitates the regional ions, causing frictional heat that extends to adjacent tissue by conduction. When the local heat reaches the temperature of 50°C, intracellular protein denaturation and melting of lipid bilayers result in coagulative necrosis [23]. To produce the same coagulation *in vivo*, 58°C is necessary due to tissue perfusion by vessels carrying away the delivered heat [24, 25]. Possibly, maintaining 60°C for 2 min also contributed to the successful results in our patients.

Clinical successes in most series reporting on primary RFA for osteoid osteomas varied between 73–95% [6, 8, 13, 15, 20]. Most patients experience pain relief within the first week and the remaining within 2 weeks after RFA. Patients may bear weight immediately and return to normal daily activities, even sports [12, 14–16]. Persistent post-procedural pain for two weeks is an indication for a second RFA to be performed [14]. Recurrences can occur in up to 11%, usually within the first 7 months after RFA [16]. Repeat RFA for persistent or recurrent symptoms has been successful in 60–100% [15, 16, 18, 20]. Advanced age and multiple ablations at the same RFA session were associated with decreased risk for recurrence [28]. In our study, all patients had complete pain relief within the first week after RFA; 96% remained asymptomatic at the latest follow-up and 4% experienced recurrence at a mean 6 months after RFA. Repeat RFA was successful in 92%. We did not find any association with age and recurrence. However, we concur that persistent or recurrent pain may occur by incomplete ablation and remnant areas of nidus at the periphery of round or the ends of elongated, multiform or large lesions [14, 15, 28]; in these cases, multiple ablations at the same RFA session are necessary to reduce the risk of recurrence [20, 28]. The 96% success rate after one RFA session in our series was higher than the 76% success rate reported by Vanderschueren et al. [16] and the 89.5% success rate reported by Rosenthal et al. [20]. Our 4% recurrence rate was also lower than that reported in the aforementioned series. It is possible that maintaining 60°C for 2 min to reduce TI and gradually increasing to 90–93°C for 14–15-minute ablation in our study is more effective compared to increasing directly to the maximum temperature and perform 4–6-minute ablation. Another possible explanation for the different success rates in these series is the selection of patients. Spinal lesions were not reported by Rosenthal et al. [20] or our series, but were included in the series of Vanderschueren et al. [16]. Spinal osteoid osteomas can be treated in a similar technique [26]. However, because of the more complex approaches, possible risks from heat transmission to spinal tissue, lower energy of delivery and different calibre electrodes we have chosen to evaluate RFA for spinal osteoid osteomas in a separate study. Accurate needle positioning and multiple ablations at the same RFA session for large and multiform osteoid osteomas, as in the series of Rosenthal et al. [20] and the present series may also have contributed to the higher success rate. When repeat procedures were included in the analysis of results by Vanderschueren et al. [16], their success rate also increased to 92%. Possible complications of RFA include bleeding, infection, pathological fracture, injury to adjacent neural structures, abscess formation, and skin and muscles burns [18, 29]. Variable increase in blood pressure, heart and respiratory rate may occur, which normalize when the lesion is completely ablated [18, 20]. In our series, even at 14–15-minute ablation, complications occurred in only 5 patients (1%). Based on these, RFA should be considered safe.

Most osteoid osteomas can be reliably diagnosed by imaging [15]. Larger size, medullary location, less surrounding sclerosis and periosteal reaction may differentiate

osteoid osteoma-mimicking lesions from osteoid osteomas, although the former may be also safely and successfully treated by RFA [27]. Percutaneous biopsy has been reported as yielding reliable results in only 50% of osteoid osteomas [13, 15]; in our study, biopsy was diagnostic in only 17%. Although in typical cases histological confirmation may not be required, a biopsy is mandated to obtain accurate diagnosis when clinical and imaging manifestations are ambiguous.

We see several limitations in this retrospective study. First, the patients were not randomized to either group, and the sample is quite heterogeneous with regards to the lesions' site and size. Second, several treatment parameters were changed simultaneously that makes difficult to determine which one accounted for the improved outcome. Third, learning curve dependent reasons for failures in the first study period and successes in the second period cannot be excluded. Given that procedures were performed by the same operators this learning bias may be substantial. Although we did not control for the learning curve since it has not been previously found an independent factor for failures [28], we acknowledge that the initial steep learning curve may have contributed to failures, and the improved expertise may have played a major role in improving successes, at least through the modifications performed over time.

In the past, we planned RFA for osteoid osteomas in the beginning with the objective of a minimally invasive, outpatient treatment. Then we saw that our results were not satisfactory. Seeing that most failures were probably due to eccentric placement of the electrode and low ablation time at 90–93°C, we revised our protocol using contiguous 1-mm slice CT for better guidance, new type of electrode with smaller calibre active tip (20 G/0.9 mm), and increased ablation time (14–15 min) after maintaining 60°C for 2 min to reduce TI. Our referral to improve outcome considered also the morphology and size of osteoid osteomas; for round 5–10 mm osteomas a single ablation is sufficient if the probe is centered in the nidus; for larger round or oval and multiform osteomas at least two ablations at the same RFA session are necessary. Safety measures were also obtained including a distance of >15 mm from neurovascular structures and >10 mm from skin when delivering high energy, and low energy delivery for superficial lesions and lesions in the bones of the hands and feet. By using these modifications, successes increased and failures reduced significantly. Nowadays, based on the experience gained over the years, we would recommend RFA for all patients with osteoid osteomas, if performed properly.

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