



Percutaneous thermal ablation for treatment of osteoid osteoma: a systematic review and analysis

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Abstract

Objective Although radiofrequency ablation is well validated for treatment of osteoid osteoma, newer technologies, namely cryoablation, have been less thoroughly studied. The purpose is to perform a systematic review and pooled analysis of percutaneous ablation technologies for treatment of osteoid osteoma with subset analysis of intra-articular and spinal tumors.

Material and methods A total of 36 of 79 identified manuscripts met inclusion criteria, comprising 1863 ablations in 1798 patients. Inclusion criteria were (1) retrospective or prospective analysis of thermal ablation of osteoid osteomas in any location, (2) at least 6 months of clinical follow-up, (3) 10 or more patients, (4) patients not included in a second study included in this review, and (5) English language or English translation available. Success rate was defined as all ablations minus technical failures, clinical failures, and recurrences. Subset analysis of intra-articular and spinal tumors was performed.

Results Overall success rate was 91.9% (95% CI 91–93%). Technical failure, clinical failure, and recurrence rates were 0.3%, 2.1%, and 5.6% respectively. Complications were seen in 2.5% (95% CI 1.9–3.3%) patients. There was no significant difference when comparing radiofrequency ablation and cryoablation ($p = 0.92$). Success rates for intra-articular (radiofrequency ablation) and spinal tumors (radiofrequency and cryoablation) were 97% and 91.6% respectively.

Conclusion Percutaneous ablation of osteoid osteomas was highly successful with low complication rates. Efficacy of radiofrequency ablation and cryoablation is similar, which is consequential because cryoablation is associated with decreased pain, predictable nerve regeneration, and theoretical immunotherapy benefits. Treatment of more challenging intra-articular and spinal lesions demonstrated similarly high success and low complication rates.

Keywords Osteoid osteoma · Percutaneous ablation · Radiofrequency ablation · Cryoablation · Meta-analysis · Microwave ablation · Bone tumor

Introduction

Osteoid osteoma (OO) is a benign bone tumor that represents 5% of all bone tumors [1–3]. They usually present in the second decade of life, most commonly before the age of 20 [1]. OOs typically occur in the long bones, particularly in the lower extremities, but less frequently can occur in the axial skeleton. Although most OOs are extra-articular, some can be intra-articular, most commonly affecting the hip joint. The most frequent presenting symptom is chronic nocturnal pain which improves with non-steroidal anti-inflammatory medications [1].

For patients with chronic pain refractory to medical management, percutaneous ablation is the treatment of choice due to its high success rate and favorable side effect profile compared with surgical resection [1]. This procedure involves percutaneous placement of an ablation probe in the center of, or

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adjacent to, the nidus under imaging guidance (typically CT, cone beam CT, or in some cases MRI) and using either rapid heating or freezing and thawing to treat the lesion.

The first ablation technology used for the treatment of OOs was radiofrequency ablation (RFA), first described in the early 1990s [4–6]. This technology uses radiofrequency waves to induce coagulation necrosis of all tissue in a defined ablation zone surrounding the probe. Many retrospective and prospective trials have been performed since then, with a systematic review reporting successful resolution of symptoms in 95% of patients treated with RFA [7].

More recently, new ablation technologies have been used to treat OOs. Cryoablation, first described for the treatment of OOs in 2010, uses argon gas or carbon dioxide to induce cell death with cycles of rapid freezing and thawing with a temperature below $-40\text{ }^{\circ}\text{C}$ [8]. This has the theoretical benefits of decreased pain during and after the procedure, which may limit the need for post-procedure pain medication. Additionally, the proceduralist has the ability to monitor the ablation zone by using CT during the procedure. Recent studies have also suggested that cryoablation, by causing the tissue necrosis without causing destruction of the intracellular contents, can promote an immune response to tumor cells outside the ablation zone, known as an abscopal effect [9]. Finally, there is evidence that nerves regenerate at a predictable rate when inadvertently or intentionally cryoablated, potentially rendering cryoablation a safer option for tumors in close proximity to nerves [10].

Microwave (MW) ablation, first described for OO treatment in 2014, uses microwaves to thermally ablate tumors [11, 12]. Microwave ablation can propagate further through tissues and is less affected by the type of tissue or tissue impedance than RFA [13].

Two subtypes of OOs warrant separate attention due to their challenging anatomical locations: 1) intra-articular OOs and 2) spinal OOs. Intra-articular lesions occur in approximately 13% of patients and present particular therapeutic challenges [14, 15]. Surgical excision is especially morbid, sometimes requiring prophylactic internal fixation of the bone [14]. Additionally, there are theoretical complications associated with the ablation of intra-articular lesions such as joint damage and injury to cartilage. Nevertheless, studies have shown high success rates in treatment of intra-articular lesions with RFA [14, 16].

Spinal OOs occur in approximately 10% of patients with OO [2, 3]. Ablation of spinal osteoid osteomas presents additional risk for nerve injury, especially in cases located close to nerve roots or the thecal sac. Surgical excision also presents increased risks, and some studies have shown high success and low complication rates with RFA of spinal osteoid osteomas [17–19].

Although RFA has a well-validated modality for the treatment of OO, the efficacy of other ablative technologies, such

as cryoablation and MW ablation, has been less thoroughly studied. Because of the previously mentioned potential advantages of cryoablation and MW ablation (as compared with RFA), comparison of different ablative modalities is warranted. As the literature studying MW ablation of OO is currently very limited, a scientifically valid comparison can only be pursued between RFA and cryoablation. Additionally, the efficacy of percutaneous ablation for OOs in intra-articular and spinal locations has similarly only been evaluated with small, retrospective case series. Thus, the primary purpose of this manuscript is to perform a systematic review of the literature comparing the efficacy and safety of RFA and cryoablation in the treatment of OO. A secondary purpose of this systematic review is to analyze the efficacy of percutaneous ablation of OOs in intra-articular and spinal locations.

An associated abstract entitled *Percutaneous thermal ablation for treatment of osteoid osteoma: a systematic review and analysis* was presented at the 2019 annual meeting for the Cardiovascular and Interventional Radiological Society of Europe [20].

Materials and methods

This retrospective study was determined to be exempted by the Institutional Review Board and was performed in compliance with the Health Insurance Portability and Accountability Act. A search for published manuscripts was performed using PubMed, the Cochrane Library, Embase, and ClinicalTrials. The keywords “osteoid osteoma,” “ablation,” “thermocoagulation,” “radiofrequency,” “cryoablation,” and “microwave” were used in different combinations. Additionally, references from identified manuscripts were screened for further studies. A total of 79 studies were initially identified.

Studies were included if they met the following criteria: (1) retrospective or prospective analysis of RFA, cryoablation, or MW ablation of osteoid osteomas; (2) at least 6 months of clinical follow-up after treatment; (3) included at least 10 patients, including initial treatment as well as patients previously treated with ablation or surgery; (4) no patients also evaluated in a second study included in this review; and (5) English language or English translation available. Additionally, studies were excluded if they performed some other type of treatment, such as alcohol or laser ablation, in combination with RFA, cryoablations, or MW ablation.

Studies in which some but not all patients were followed for 6 months were included only if the outcomes were reported separately for those patients. Only the patients that were followed clinically for 6 months were included in the analysis. The search was performed using a predetermined search strategy, and the data extraction was based on a predefined data form. The Quality Appraisal Checklist for Case Series Studies

Table 1 Included studies sorted by ablation technology

Article no.	Reference no.	Lead author	Year	Title	No. ablations	Technology	Patient population
1	[23]	Coupal	2014	CT-guided percutaneous cryoablation for osteoid osteoma: initial experience in adults	10	Cryoablation	Adults
2	[24]	Santiago	2018	Percutaneous cryoablation for the treatment of osteoid osteoma in the adult population	22	Cryoablation	Adults
3	[25]	Shah	2018	Long-term results and durability of cryoablation of osteoid osteoma in the pediatric and adolescent population	63	Cryoablation	Children
4	[11]	Kostrzewa	2014	Microwave ablation of osteoid osteomas using dynamic MR imaging for early treatment assessment: preliminary experience	10	Microwave ablation	Both
5	[26]	Abboud	2016	Long-term clinical outcomes of dual-cycle radiofrequency ablation technique for treatment of osteoid osteoma	24	RFA	Both
6	[27]	Akhlaghpoor	2010	Radiofrequency ablation of osteoid osteoma in atypical locations: a case series	21	RFA	Both
7	[16]	Albisinni	2014	Treatment of osteoid osteoma of the elbow by radiofrequency thermal ablation	28	RFA	Both
8	[17]	Albisinni	2017	Spinal osteoid osteoma: efficacy and safety of radiofrequency ablation	62	RFA	Both
9	[28]	Al-Omari	2012	Radiofrequency ablation of osteoid osteoma using tissue impedance as a parameter of osteonecrosis	31	RFA	Both
10	[29]	Becce	2010	Osteoid osteoma and osteoid osteoma-mimicking lesions: biopsy findings, distinctive MDCT features and treatment by radiofrequency ablation	65	RFA	Both
11	[30]	Bourgault	2014	Percutaneous CT-guided radiofrequency thermocoagulation in the treatment of osteoid osteoma: a 87 patient series	91	RFA	Both
12	[31]	Cantwell	2006	Radiofrequency ablation of osteoid osteoma with cooled probes and impedance-control energy delivery	11	RFA	Both
13	[32]	Cheng	2014	Radiation dosimetry of intraoperative cone-beam compared with conventional CT for radiofrequency ablation of osteoid osteoma	66	RFA	Both
14	[33]	Cioni	2004	CT-guided radiofrequency ablation of osteoid osteoma: long-term results	44	RFA	Both
15	[34]	Daniilidis	2012	Percutaneous CT-guided radio-frequency ablation of osteoid osteoma of the foot and ankle	31	RFA	Both
16	[35]	Donkol	2008	Efficacy of percutaneous radiofrequency ablation of osteoid osteoma in children	23	RFA	Children
17	[36]	Garge	2017	Radiofrequency ablation of osteoid osteoma in common and technically challenging locations in pediatric population	31	RFA	Children
18	[37]	Ghanem	2003	Percutaneous radiofrequency coagulation of osteoid osteoma in children and adolescents	25	RFA	Both
19	[38]	Hage	2018	Percutaneous radiofrequency ablation for the treatment of osteoid osteoma in children and adults: a comparative analysis in 92 patients	100	RFA	Both
20	[39]	Hoffmann	2010	Radiofrequency ablation in the treatment of osteoid osteoma-5-year experience	35	RFA	Both
21	[40]	Karagoz	2016	Effectiveness of computed tomography guided percutaneous radiofrequency ablation therapy for osteoid osteoma: initial results and review of the literature	18	RFA	Both
22	[18]	Martel	2009	Osteoid osteoma of the spine: CT-guided monopolar radiofrequency ablation	12	RFA	Both
23	[19]	Morassi	2014	Percutaneous radiofrequency ablation of spinal osteoid osteoma under CT guidance	15	RFA	Both
24	[41]	Mylona	2010	Osteoid osteomas in common and in technically challenging locations treated with computed tomography-guided percutaneous radiofrequency ablation	25	RFA	Both
25	[42]	Neumann	2012	Follow-up of thirty-three computed-tomography-guided percutaneous radiofrequency thermoablations of osteoid osteoma	34	RFA	Both
26	[14]	Papagelopoulos	2006	Radiofrequency ablation of intra-articular osteoid osteoma of the hip	16	RFA	Both
27	[43]	Peysers	2007	Osteoid osteoma: CT-guided radiofrequency ablation using a water-cooled probe	52	RFA	Both
28	[44]	Peysers	2009	CT-guided radiofrequency ablation of pediatric osteoid osteoma utilizing a water-cooled tip	23	RFA	Children

Table 1 (continued)

Article no.	Reference no.	Lead author	Year	Title	No. ablations	Technology	Patient population
29	[3]	Rimondi	2012	Radiofrequency ablation for non-spinal osteoid osteomas in 557 patients	581	RFA	Both
30	[45]	Rosenthal	2003	Osteoid osteoma: percutaneous treatment with radiofrequency energy	126	RFA	Both
31	[46]	Santiago	2011	Percutaneous treatment of bone tumors by radiofrequency thermal ablation	14	RFA	Both
32	[47]	Schmidt	2011	CT-guided radiofrequency (RF) ablation of osteoid osteoma: clinical long-term results	23	RFA	Both
33	[48]	Shields	2018	Radiofrequency ablation for osteoid osteoma - recurrence rates and predictive factors	42	RFA	Both
34	[49]	Soong	2006	Radiofrequency ablation of osteoid osteoma in the upper extremity	25	RFA	Both
35	[50]	Sung	2009	Computed-tomography-guided percutaneous radiofrequency thermoablation for the treatment of osteoid osteoma-2 to 5 years follow-up	32	RFA	Both
36	[51]	Vanderschueren	2009	Radiofrequency ablation of spinal osteoid osteoma: clinical outcome	32	RFA	Adults

was applied to each included study to assess its quality [21, 22].

Success was defined as a resolution to the patient's pain without recurrence through the entire follow-up period. "Success rate" refers to the percentage of cases without technical failures (i.e., the ablation probe could not be successfully placed in or near the OO nidus or the procedure could not be completed), clinical failures (i.e., patients in whom the pain never resolved following treatment), or recurrences (i.e., patients in whom pain resolved for a period of time but then recurred). Patients who had a failure or recurrence but received a second successful treatment were counted twice, once as a failure/recurrence and once as a success (if adequate clinical follow-up was documented).

Data analysis

To compare different technologies (RFA vs cryoablation), logistic regression models were fitted for each outcome of interest (success, technical failures, clinical failures, recurrences, and complications) on the pooled data. Probabilities with 95% confidence intervals for overall sample and each technology groups were determined. Due to the small sample size, the MW ablation group ($n = 1$) was not included in this analysis. The group-specific probability of technical failures was not estimable because the number of observed events was too small. Multinomial regression analysis were also conducted to take into account that all outcomes sum up to the total sample size. All analyses were performed with SAS v9.4 (SAS Institute, Cary, NC).

Results

A total of 79 studies were identified, and 36 studies met the inclusion criteria, published between 2003 and 2018 (Table 1). A total of 1863 ablations in 1798 patients were included in this review. Of the included studies, 32 (88.9%) evaluated RFA, 3 (8.3%) evaluated cryoablation, and 1 (2.8%) evaluated MW ablation. Three studies (8.3%) included only adult patients, 4 (11.1%) included only children, and 29 (80.6%) included both. The mean age at time of procedure was 18.7 years (range 2 to 68 years). The mean ages for RFA, cryoablation, and MW ablation were 18.7, 17.5, and 28 years respectively. In 13 (36%) studies, biopsy was performed on all lesions. In 23 (64%) studies, biopsy was not performed on some or all lesions prior to ablation.

Successes, failures, and recurrences for each study are detailed in Table 2. Results of the pooled analysis are reported in Table 3. Overall success rate was 91.9% (95% confidence interval 91–93%). Success rates were 91.9%, 91.6%, and 100% for RFA, cryoablation, and MW respectively, without significant difference when comparing cryoablation and RFA ($p = 0.92$). Technical failure, clinical failure, and recurrence rates were 0.3%, 2.1%, and 5.6% respectively.

Technical failures, occurring in 0.3% (95% confidence interval 0.2%–0.7%), included shortened ablation time due to concern for developing hyperthermia in one case and concern about close proximity to the neurovascular bundle in another, failure to localize the lesion due to heavy sclerosis in one patient, inability to penetrate the sclerotic rim in one patient, and damage to the machine cable in one case.

Complications were seen in 2.5% (95% confidence interval 1.9–3.3%) of procedures. Major complications

Table 2 Reported success rate, failures, and recurrences

Article no.	Reference no.	Lead author	Technology	No. ablations	Success rate	No. technical failures	No. clinical failures	No. recurrences	No. complications
1	[23]	Coupal	Cryoablation	10	100.00%	0	0	0	0
2	[24]	Santiago	Cryoablation	22	95.45%	0	0	1	3
3	[25]	Shah	Cryoablation	63	88.89%	0	2	5	2
4	[11]	Kostrzewa	Microwave ablation	10	100.00%	0	0	0	0
5	[26]	Abboud	RFA	24	100.00%	0	0	0	1
6	[27]	Akhlaghpoor	RFA	21	100.00%	0	0	0	0
7	[16]	Albisinni	RFA	28	96.43%	0	0	1	0
8	[17]	Albisinni	RFA	62	93.55%	0	0	4	1
9	[28]	Al-Omari	RFA	31	93.55%	0	1	1	2
10	[29]	Becce	RFA	65	90.77%	0	0	6	2
11	[30]	Bourgault	RFA	91	89.01%	0	0	10	7
12	[31]	Cantwell	RFA	11	100.00%	0	0	0	0
13	[32]	Cheng	RFA	66	87.88%	0	0	8	0
14	[33]	Cioni	RFA	44	79.55%	0	9	0	2
15	[34]	Daniilidis	RFA	31	83.87%	0	2	3	0
16	[35]	Donkol	RFA	23	69.57%	2	3	2	5
17	[36]	Garge	RFA	31	96.77%	0	1	0	1
18	[37]	Ghanem	RFA	25	92.00%	0	2	0	0
19	[38]	Hage	RFA	100	92.00%	0	2	6	2
20	[39]	Hoffmann	RFA	35	88.57%	1	0	3	4
21	[40]	Karagoz	RFA	18	94.44%	0	0	1	3
22	[18]	Martel	RFA	12	83.33%	0	2	0	0
23	[19]	Morassi	RFA	15	86.67%	0	2	0	0
24	[41]	Mylona	RFA	25	92.00%	0	0	2	0
25	[42]	Neumann	RFA	34	97.06%	0	0	1	0
26	[14]	Papagelopoulos	RFA	16	100.00%	0	0	0	0
27	[43]	Peysen	RFA	52	96.15%	1	0	1	1
28	[44]	Peysen	RFA	23	91.30%	0	1	1	0
29	[3]	Rimondi	RFA	581	95.52%	0	0	24	5
30	[45]	Rosenthal	RFA	126	88.89%	0	5	9	2
31	[46]	Santiago	RFA	14	92.86%	0	0	1	1
32	[47]	Schmidt	RFA	23	100.00%	0	0	0	2
33	[48]	Shields	RFA	42	83.33%	0	0	7	0
34	[49]	Soong	RFA	25	76.00%	2	4	0	0
35	[50]	Sung	RFA	32	84.38%	0	0	5	0
36	[51]	Vanderschueren	RFA	32	84.38%	0	3	2	0

reported in studies evaluating RFA included one bone infarction requiring surgery, one soft-tissue infection severe enough to require surgical debridement, one skin burn requiring skin graft, one case of flash pulmonary edema resulting in 15 days of intubation, and one patient who developed complex regional pain syndrome 2 years following treatment. The access needle broke in three cases, one of which required surgical removal. Transient self-resolving paresthesias, the longest-lasting 30 days, were seen in three patients. Two patients

developed contractures (finger and ankle) successfully treated with physical therapy. The remainder of complications were minor skin burns, skin and soft-tissue infections treated with antibiotics, a self-resolving hematoma, and a case of superficial thrombophlebitis. Studies evaluating cryoablation reported two patients with overnight admissions for pain, two cases of transient soft-tissue swelling, and one minor skin burn. No complications were reported in the study evaluating MW ablation.

Table 3 Results of the pooled analysis

	All (<i>n</i> = 35)		RFA (<i>n</i> = 32)		Cryoablation (<i>n</i> = 3)		<i>p</i> value for between technology difference
	Probability	95% CI	Probability	95% CI	Probability	95% CI	
Successes	91.9%	(91%, 93%)	91.9%	(88%, 94%)	91.6%	(84%, 96%)	0.92
Technical failures	0.3%	(0.2%, 0.7%)	Too few events, not estimable				
Clinical failures	2.1%	(1.5%, 2.9%)	2.1%	(1.0%, 4.2%)	2.1%	(0.5%, 8.0%)	> 0.99
Recurrences	5.6%	(4.7%, 6.8%)	5.9%	(4.0%, 8.8%)	6.3%	(2.9%, 13.4%)	0.76
Complications	2.5%	(1.9%, 3.3%)	3.5%	(2.2%, 5.5%)	5.3%	(2.2%, 12%)	0.12

MW ablation was not included in the pooled analysis due to limited number of studies

In 13 (36.1%) studies, some or all patients were treated for intra-articular lesions (Table 4). A total of 157 ablations were performed on intra-articular lesions. For many treated lesions, based on the data provided, the success rate could not be determined; however, for the seven studies in which these patients could be analyzed separately based on the previously stated inclusion criteria, the success rate was 97.0%.

In 12 studies (33.3%), some or all patients were treated for spinal OOs (Table 5). A total of 142 ablations were performed on spinal lesions. As with intra-articular lesions, for many spinal lesions, the success rate could not be determined; however, for the nine studies in which these patients could be analyzed separately, the overall success rate was 91.6%.

Discussion

With an overall success rate of 91.9% and an overall complication rate of 2.5%, the results of this review reinforce the findings of previous studies that percutaneous thermal ablation of OOs is a safe and effective therapeutic alternative to open surgery [3, 7,

45]. RF and cryoablation demonstrated statistically similar outcomes. This finding is particularly salient, given some additional benefits of cryoablation over heat-based technologies. For example, a study evaluating patient response to different technologies for ablation of bony metastases demonstrated significantly decreased pain, analgesic use, and hospital length of stay with cryoablation compared with RFA, findings which may be applicable to treatment of osteoid osteomas as well [52].

Moreover, emerging evidence suggests that cryoablation may have an abscopal, or immunotherapy benefit, in addition to eliminating the risk of permanent nerve damage [9, 10]. Additionally, further evidence demonstrates that both motor and sensory nerves regenerate following (intentional and unintentional) cryoablation, which may improve the safety of ablations near critical nerves and spinal cord [10]. While additional studies are necessary to prove the merit of these scientifically based claims, the findings of this review confirm at least equal efficacy between the two (RF and cryoablation) modalities for the treatment of OOs. MW ablation, alternatively, while demonstrating promising results, lacks available literature for statistical comparison of efficacy.

Table 4 Studies that describe treatment of intra-articular lesions

Article no.	Reference no.	Lead author	Technology	No. intra-articular ablations	No. successful intra-articular ablations
5	[26]	Abboud	RFA	2	2
6	[27]	Akhlaghpoor	RFA	6	6
7	[16]	Albisinni	RFA	28	27
9	[28]	Al-Omari	RFA	2	Not reported
13	[32]	Cheng	RFA	14	Not reported
17	[36]	Garge	RFA	4	Not reported
18	[37]	Ghanem	RFA	2	2
19	[38]	Hage	RFA	3	Not reported
24	[41]	Mylona	RFA	3	Not reported
26	[14]	Papagelopoulos	RFA	16	16
27	[43]	Peyser	RFA	7	7
28	[44]	Peyser	RFA	5	4
29	[3]	Rimondi	RFA	65	Not reported

Table 5 Studies that describe treatment of spinal lesions

Article no.	Reference no.	Lead author	Technology	No. spinal ablations	No. successful spinal ablations
2	[24]	Santiago	Cryoablation	5	5
8	[17]	Albisinni	RFA	62	58
11	[30]	Bourgault	RFA	1	1
12	[31]	Cantwell	RFA	1	1
13	[32]	Cheng	RFA	1	1
19	[38]	Hage	RFA	1	Not reported
20	[39]	Hoffmann	RFA	5	Not reported
22	[18]	Martel	RFA	12	12
23	[19]	Morassi	RFA	15	13
24	[41]	Mylona	RFA	5	Not reported
27	[43]	Peyser	RFA	2	2
36	[51]	Vanderschueren	RFA	32	27

The majority of failures were due to recurrent disease (5.6% for all modalities). Clinical failures (i.e., patients who never experienced pain relief following treatment) only occurred following 2.5% of procedures, and there was nearly a 100% technical success rate with all modalities. A total of 74 of the 104 patients (71.2%) with disease recurrence were successfully treated with a second ablation. While most recurrences occurred in the first few months following initial ablation, some occurred years after the initial treatment (median = 7 months, mean = 10.8 months, range = 1 month to 6 years). This highlights the importance of long-term clinical follow-up in this patient population.

Regarding anatomical location of OOs, because of the more challenging location and theoretical complications associated with the treatment of intra-articular lesions (e.g., joint damage and injury to cartilage), special attention was given to ablation of OOs in this location. Because the numbers of intra-articular lesions in studies were often very small, a direct comparison is difficult to make. Nevertheless, in the studies evaluating only intra-articular lesions, success and complication rates were similar to that of all lesions, with no joint-specific complications reported over at least a 6-month clinical follow-up interval [14, 16]. This study is limited, however, because it cannot determine the risk of chondrolysis and subsequent osteoarthritis which would likely take years to develop.

Similar to intra-articular OOs, spinal lesions were analyzed because of the proximity to critical structures such as nerve roots and the spinal cord. Nevertheless, no permanent neurologic complications were reported in the included studies, with only one case of a spontaneously resolving lower limb paresthesia that lasted for 30 days [17]. The success rates were also comparable to that of all lesions.

In 23 (64%) studies, the proceduralist did not biopsy some or all lesions prior to ablation. Because of the high specificity of cross-sectional imaging in the diagnosis of OO and negative or inconclusive biopsy results in many cases, some

providers viewed this as an unnecessary step [1, 2]. In the studies included in this review, 766 biopsies were performed with only 59.3% diagnostic for osteoid osteoma. While detailed analysis of the non-diagnostic results is limited by heterogeneous methodology and lack of detailed breakdown in most of the included studies, the vast majority were either reported to be non-diagnostic, normal bone tissue, or merely suggestive of OO. Nevertheless, Becce, et al. reported 10 OO mimic lesions out of 65 biopsied (5 chronic osteomyelitis, 3 chondroblastoma, 1 eosinophilic granuloma, 1 fibrous dysplasia) [29]. Consequently, although biopsy may not have a key role in the diagnosis of OO, the authors recommend its use in order to rule out other pathology, especially because it can be performed during the same procedure immediately prior to ablation without a delay in care or additional procedure. This is particularly important as the ablation changes the imaging appearance of the lesion and may confound subsequent evaluation.

There are some limitations to this review. Because they are relatively new techniques for treatment of osteoid osteoma, fewer papers evaluating the use of cryoablation and MW ablation were available. This limited the comparison between modalities. Additionally, MRI-guided high-intensity focused ultrasound (MgHIFU) has been shown to be effective for treatment for certain OOs with recurrence rates reported at 87% in the largest study [53]. Nevertheless, the indications for percutaneous ablation and MgHIFU are not entirely overlapping, given the exclusion of spinal lesions in the largest study and a separate technical feasibility study reporting that only 50% of OOs are amenable to treatment with MgHIFU alone [53, 54]. Moreover, only one identified study met the inclusion criteria of ten or more patients [53]. Thus, MgHIFU was not analyzed in this study.

Furthermore, only manuscripts with 10 patients or more were included. This small number decreases the power of the statistical analysis. Importantly, this cohort size

requirement, albeit small, likely excluded some studies of cryoablation and MW ablation due to their recent emergence for use in treatment of OO. For similar reasons, studies with at least 6 months of follow-up were included, but many recurrences occur much later than that time period. Consequently, recurrent disease is likely underestimated in this review. Finally, patient population, lesion location, procedural practices, and definitions of complications and clinical failures differed across the included studies.

In conclusion, percutaneous ablation of osteoid osteomas was successful in 91.9% of patients with a very low (approximately 2.5%) complication rate. Success and complication rates between RFA and cryoablation were similar, which suggests that cryoablation may be preferential in most circumstances given its additional benefits, namely decreased post-procedure pain, predictable nerve regeneration, and theoretical immunotherapy effects. MW ablation, while demonstrating promising early results, still requires more published data for comparative efficacy. Finally, treatment of more challenging intra-articular and spinal lesions demonstrated success and complication rates similar to OO treated in more traditional anatomic locations.

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

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