

Osteoid Osteoma Treated by Percutaneous Thermal Ablation: When Do We Fail? A Systematic Review and Guidelines for Future Reporting

Ezio Lanza · Yann Thouvenin · Pierre Viala · Luca Maria Sconfienza · Dario Poretti · Gianpaolo Cornalba · Francesco Sardanelli · Catherine Cyteval

Received: 10 October 2013 / Accepted: 24 November 2013 / Published online: 13 December 2013

© Springer Science+Business Media New York and the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) 2013

Abstract

Purpose Osteoid osteoma (OO) is a painful benign bone tumor of the young that is widely treated by percutaneous thermal ablation (PTA) with success rates close to 100 %. Nevertheless, some patients have recurrences. We reviewed the literature to understand whether these are true recurrences or incomplete treatments; to analyze safety and efficacy during long-term follow-up in a extremely large cohort of patients; to detail best-practice suggestions from the largest clinical trials as well as report their complications; and to recommend standards for future reporting.

Materials and Methods This study followed the Cochrane's guidelines for Systematic Reviews of Interventions. Inclusion criteria were as follows: (1) prospective or retrospective cohort study for PTA of OO under computed

tomography (CT) guidance; (2) CT or magnetic resonance diagnosis; (3) radiofrequency ablation or interstitial laser ablation technique; (4) English language; (5) population <10 patients; (6) follow-up ≥ 12 months; and (7) original research. Risk of bias was assessed with a modified Newcastle–Ottawa Scale.

Results Two hundred fourteen articles were initially found. After applying the criteria mentioned previously, 27 PTA articles concerning 1,772 patients were chosen for inclusion. No exclusions were made due to risk of bias.

Conclusion The investigators proved the long-term efficacy and superiority of PTA for OO compared with other techniques. In 5 % of patients, however, the technique failed, and the researchers did not offer detailed exhaustive explanations. Future clinical trials for OO ablation should consider reporting essential procedure details and follow-up findings to allow for a meta-analysis. We provide both recommended standards for future reporting and suggestions for the prevention of recurrence.

Keywords Clinical practice · Interventional oncology · Ablation · Skeletal interventions · Pain management · Bone · Pain

E. Lanza (✉) · L. M. Sconfienza · G. Cornalba · F. Sardanelli
Dipartimento di Scienze della Salute, Scuola di specializzazione in Radiodiagnostica, U.O. di Radiologia Diagnostica e Interventistica, Ospedale San Paolo, Università Degli Studi di Milano, Via Antonio di Rudini, 8, 20142 Milan, Italy
e-mail: eziolanza@gmail.com

Y. Thouvenin · P. Viala · C. Cyteval
Imagerie Médicale, Hôpital Lapeyronie - CHU de MONTPELLIER, 191 Avenue du Doyen Gaston Giraud, 34000 Montpellier, France

L. M. Sconfienza · F. Sardanelli
Dipartimento di Scienze Biomediche per la Salute, Unità di Radiologia, IRCCS Policlinico San Donato, Università degli Studi di Milano, Via Morandi 30, 20097 San Donato Milanese, MI, Italy

D. Poretti
Dipartimento di Radiologia, Sezione di Radiologia Interventistica, Humanitas Clinical and Research Center, Via Alessandro Manzoni, 56, 20089 Rozzano, MI, Italy

Introduction

Osteoid osteoma (OO) is a benign bone tumor of the young that typically presents with chronic pain at the extremities, which spikes at night. Surgical excision has been the “gold standard” of treatment until 1992, when Rosenthal et al. [1] reported the first percutaneous thermal ablation (PTA), more precisely, computed tomography-guided radiofrequency ablation (CT-RFA) (Figs. 1, 2). Since then, a plethora of clinical trials have reported success rates close

Fig. 1 Large cortical OO of the tibia (*white arrow*) in a 7-years old boy before (A) and after (B) RF needle insertion

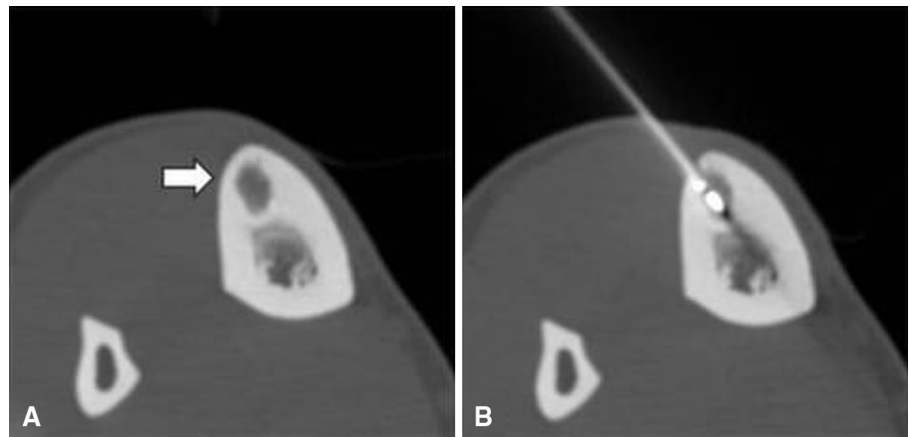
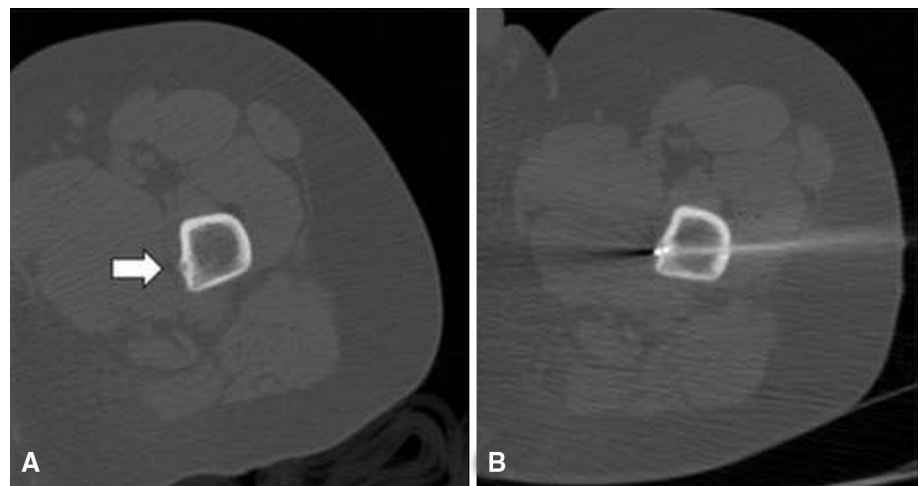


Fig. 2 Small OO of the medial cortex of the femur (*white arrow*) in a 23-years old man before (A) and after (B) RF needle insertion



to 100 %, thus making PTA the treatment of choice. Advantages over surgery include low invasiveness of percutaneous versus open access, minimal postinterventional observation, ability to treat high-risk localizations, such as intra-articular and spinal localizations, and lower cost.

A minority of patients, however, have only a partial response. In some case, the investigators report an unsuccessful technique; nevertheless, it is accepted that a small percentage of patients will have a symptomatic recurrence even after several pain-free months no matter how satisfactory the procedure initially was.

The present study aimed to assess the incomplete and recurrent cases of OO treated by PTA the literature and to enlist the causes and the suggestions reported by the investigators. Second, we analyzed the overall safety and efficacy of PTA during long-term follow-up and classified the incidence of OO in relation to anatomical size and patient age in a large cohort of patients. Third, we detailed a sizable number of complications and the reported methods to prevent them. To our knowledge, this is the first systematic literature review of PTA of OO.

Materials and Methods

Literature Searches

This study followed the Cochrane Collaboration for Systematic Reviews of Interventions. [2]. We searched MEDLINE, MEDLINE In-Process, EMBASE, and the Cochrane databases from 1992 to 2013, targeting our search based on condition and intervention using the keywords “osteoid,” “osteoma,” “ablation,” “coagulation,” and “thermocagulation” combined in appropriate algorithms. In addition, the biographies of the resulting articles were screened for further inclusion.

Selection Criteria

All studies matching the following criteria were eligible for inclusion: (1) prospective or retrospective cohort study for PTA of OO under CT guidance; (2) patient OO diagnosis by way of at least one CT or MR examination; (3) RFA or interstitial laser ablation (ILA) as the object of the study;

(4) English language; (5) population <10 patients; (6) follow-up ≥ 12 months; and (6) results are not already published by the same investigator in a previous article. We also included those studies focused on comparison with another technique or those in which part of the cohort had undergone previous treatment for OO. Two reviewers [E. L. (radiology resident with 6 year of experience in literature research) and Y. T. (radiologist with 6 years of OO ablation practice)] assessed the studies for inclusion and resolved conflicts in consensus.

Data Extraction

Eligible articles were systematically assessed for data extraction against a precompiled electronic sheet (Excel 2011; Microsoft, Seattle, WA, USA), which takes into account the following features: study design, demographic characteristics, type of anesthesia, technical specifications, tumor localization, technical success, clinical success at multiple time points, biopsy success, postprocedural management, complications, incomplete treatments and recurrences, follow-up protocol, retreatments, patients lost to surgery, and investigators.

When an investigator reported a median age of population instead of a mean value, this was determined with a dedicated algorithm [3]. The same calculations were used when mean follow-up time was not explicitly reported.

Regarding clinical success, we considered the number of patients reporting a satisfactory treatment at different time intervals: I = 0–1 months; II = 1 month and 1 day to 6 months; III = 6 months and 1 day to 12 months; IV = 12 months and 1 day to 24 months. Particularly, the IV time was only considered when at least half the population was assessed at this follow-up point. If a patient had recurrence during one time interval and had a satisfactory retreatment in a following interval, it was counted as clinically unsuccessful during the former and as successful in the latter. If a part of a study population did not have 12-month follow-up, this subgroup was separated and excluded from the analysis [4].

Regarding biopsy, we considered it as successful when the pathologist's response was diagnostic for OO or osteoblastoma (OB). Notably, not all investigators have performed this procedure, and among those who did, just a subgroup of patients was considered suitable. Hence, our calculations for biopsy success ratio apply to these subgroups and not to the overall study cohort.

Concerning incomplete treatments, this was considered the case when the investigator specifically reported an unsatisfactory procedure, habitually realizing so before or immediately after the first postinterventional evaluation. In contrast, a recurrence was defined as a new episode of the same pain for which the patient was originally treated that

occurred after a successful procedure and a reported or deductible pain-free interval of at least 1 month. If this patient opted or was referred for surgery instead of a retreatment, this was counted as "patient referred to surgery."

Complications were defined as all perioperative events that required unpreventable medical care, such as additional clinical evaluation, prolonged observation, further imaging studies, or interventions. When a complication led to an incomplete treatment, these two were counted as distinct events. If a complication led to a surgical intervention, the patient was again counted as "patient referred to surgery." Retreatment was defined as a patient who needed more than one ablation in the same study to attain pain relief regardless of the outcome.

For each of these categories, we extrapolated and categorized the pertaining investigators' opinions of both likely causes and actions to take to avoid undesired results. Because not all articles contributed equally to the analysis, for every field we expressed the relative number of articles (n_p) that provide pertinent data (Table 1).

Methodological Quality Assessment

The assessment of quality was performed with a modified version of the Newcastle–Ottawa Scale (NOS) [5]. This scale evaluates the quality of nonrandomized studies to be included in a systematic review and uses a "star system" to judge three aspects of the study groups: (1) selection, (2) comparability, and (3) ascertainment of either the exposure or outcome of interest for case–control or cohort studies, respectively. Considering the implicit absence of a control group in the cohorts included in our review, we adapted the NOS to judge the following aspects: (I) representativeness of cohort, (II) ascertainment of exposure, (III) outcome of interest, (IV) assessment of outcome, (V) adequate duration of follow-up, and (VI) adequate follow-up of cohort. As to the answer to specific question (Table 2), an article was awarded a grade A*, B*, C, or D for each aspect, but only grades A* and B* are worth a star. Consequently, an article of the best possible quality was awarded with six stars.

Results

Two hundreds fourteen studies were initially found. After applying the criteria, 28 clinical trials were included. During the first assessment, 2 articles were excluded because the same investigator had already presented the results in a different journal. Two studies were excluded because ablation was performed with alcohol injection and cementoplasty, respectively. After reference evaluation, 3 frequently cited articles, initially not considered, were also included.

Table 1 Articles included in the analysis, sorted by year

Article no.	Reference no.	Author	Journal	Year	Title	No. of patients	No. of stars ^a	
1	[15]	Earhart	Pediatr Radiol	2013	RF	RFA in the treatment of OO: results and complications	21	6
2	[12]	Rimondi	Eur Radiol	2012	RF	RFA for nonspinal OO	557	6
3	[8]	Rehmitz	Eur J Radiol	2012	RF	CT-guided RFA of OO and OB: clinical success and long-term follow-up	77	6
4	[11]	Neumann	Int Orthop	2012	RF	Follow-up of CT-guided percutaneous RFA of OO	33	6
5	[19]	Al-Omari	J Med Imaging Radiat Oncol	2012	RF	RFA of OO using tissue impedance as a parameter of osteonecrosis	30	6
6	[20]	Danilidis	Arch Orthop Trauma Surg	2012	RF	Percutaneous CT-guided RFA of OO of the foot and ankle	29	6
7	[13]	Mahnken	J Med Imaging Radiat Oncol	2012	RF	Contrast-enhanced MRI predicts local recurrence of OO after RFA	20	6
8	[21]	Miyazaki	Jpn J Radiol	2011	RF	Percutaneous RFA of OO using cool-tip electrodes without the cooling system	17	6
9	[22]	Mahnken	Cardiovasc Intervent Radiol	2011	RF	RFA of OO: initial experience with a new monopolar ablation device	17	5
10	[9]	Roqueplan	Eur Radiol	2010	IL/A	Long-term results of percutaneous resection and ILA of OO	100	6
11	[23]	Bece	Eur Radiol	2010	RF	OO and OO-mimicking lesions: biopsy findings, distinctive MDCT features, and treatment with RFA	54	6
12	[4]	Hoffmann	Eur J Radiol	2010	RF	RFA in the treatment of OO: a 5-y experience	32	6
13	[16]	Akhlaghpour	Clin Orthop Relat Res	2010	RF	RFA of OO in atypical localizations: a case series	21	6
14	[24]	Sung	Int Orthop	2009	RF	CT-guided percutaneous RFA for the treatment of OO: 2- to 5-y follow-up	28	6
15	[25]	Vanderschueren	Spine (Phila Pa 1976)	2009	RF	RFA of OO: clinical outcome	24	6
16	[26]	Gangi	Radiology	2007	IL/A	OO: percutaneous laser ablation and follow-up	114	6
17	[27]	Peyser	Ann Surg Oncol	2007	RF	OO: CT-Guided RFA using a water-cooled probe	51	6
18	[28]	Gebauer	Cardiovasc Intervent Radiol	2006	RF-IL/A	OO: experience with laser- and RF-induced ablation	17	6
19	[10]	Mahnken	J Vasc Interv Radiol	2006	RF	RFA of OO: initial results with a bipolar ablation device	12	6
20	[29]	Martel	Eur J Radiol	2005	RF	Percutaneous RFA of OO using cool-tip electrodes	38	6
21	[30]	Cioni	Eur Radiol	2004	RF	CT-guided RFA of OO: long-term results	38	6
22	[14]	Rosenthal	Radiology	2003	RF	OO: percutaneous treatment with RF energy	263	6
23	[31]	Lindner	J Bone Joint Surg Br	2001	RF	Percutaneous RFA of OO	58	6
24	[32]	Woertler	J Vasc Interv Radiol	2001	RF	OO: CT-guided percutaneous RFA with follow-up	47	5
25	[33]	Witt	J Bone Joint Surg Br	2000	IL/A	Interstitial laser photocoagulation for treatment of OO	23	6
26	[34]	Barei	Clin Orthop Relat Res	2000	RF	Percutaneous RFA of OO	13	6
27	[1]	Rosenthal	J Bone Joint Surg Am	1999	RF	Percutaneous RF coagulation of OO compared with surgical treatment	38	6

MDCT multidetector CT, RF radiofrequency ablation, ILA interstitial laser ablation

^a According to the Newcastle–Ottawa Scale for the assessment of risk of bias

Table 2 Newcastle–Ottawa Quality Assessment scale modified by Lanza E*Selection*

1. Representativeness of the exposed cohort
 - A. *Truly representative of the average in the community
 - B. *Somewhat representative of the average in the community
 - C. Selected group of users e.g., nurses, volunteers
 - D. No description of the derivation of the cohort
2. Ascertainment of exposure
 - A. *Secure record (e.g., surgical records)
 - B. *Structured interview
 - C. Written self-report
 - D. No description
3. Demonstration outcome of interest was not present at start of study
 - A. *Yes
 - B. No

Outcome

4. Assessment of outcome
 - A. *Independent blind assessment
 - B. *Record linkage
 - C. Self-report
 - D. No description
5. Was follow-up long enough for outcomes to occur?
 - A. *Yes (select an adequate follow-up period for outcome of interest)
 - B. No
6. Adequacy of follow-up of cohorts
 - A. *Complete follow-up - all subjects accounted for
 - B. *Subjects lost to follow-up unlikely to introduce bias—small number lost
 - C. Follow-up rate <12 months and no description of those lost
 - D. No statement

* A star is awarded to the paper for this option

In total, this review comprises 27 articles (n_p) describing thermal ablation for OO concerning 1,772 patients (1,205 males, 554 females, 13 not specified; mean age = 20.8 - years; $\sigma = 2.5$) from 1998 to 2013: 23 involved RFA, 3 involved ILA, and 1 involved combined RF-ILA.

Twelve investigators (44 %) performed the ablations with the patient under general (GA) or locoregional (LR) anesthesia; 9 (33 %) under GA; 2 (7 %) did not report specifically; 2 used GA, LR, or local anesthesia (7 %); 1 (7 %) used both GA and conscious sedation (CS); and 1 investigator intervened with the patient under GA, LR or CS depending on the case.

Mean technical success was 100 % ($\sigma = 0.02$, $n_p = 27$). The OOs were located as follows: femur 41.6 %, tibia 20.1 %, not specified 10.9 %, foot 6.1 %, humerus 4.9 %, pelvis 4.9 %, spine 3.5 %, fibula 1.7 %, ulna 1.5 %, radius 1.1 %, hand 1.1 %, scapula 0.5 %, clavicle 0.1 %, and ribs 0.1 % (Fig. 3).

radius 1.1 %, hand 1.1 %, scapula 0.5 %, clavicle 0.1 %, and ribs 0.1 % (Fig. 3).

Biopsy mean rate of detection was 59 % ($\sigma = 0.24$, $n_p = 16$). The available data were insufficient to estimate the frequency of biopsy procedures in the considered population.

Electrodes or laser fibers used were as follows: 5 unspecified needles attached to a Radionics RF generator; 5 unspecified needles and generator; 4 Cool-Tip (Valleylab); 3 Diomed laser fibers (Cambridge); 2 Soloist (Boston Scientific); 2 CelonProSurge micro (Celon); 1 UniBlate (AngioDynamics); 1 RFG-3 C Radionics (Tyco Healthcare); 1 Cool-Tip (Century Medical); 1 combined Starburst (RITA)/Cool-Tip (Radionics/LeVein (Boston Scientific)/SDE (RITA)/Celon ProSurge micro (Celon) systems; 1 water-cooled 9F-Power Laser Set (Somatex) plus Starburst (RITA); and 1 (4 %) used a thermo-coupling device for temperature measurement. No substantial differences in the outcome were documented between the different needle types.

In 21 (78 %) of the articles, a coaxial approach was used. This means that the electrode/laser diode reached the nidus coaxially inserted into another device (15 bone needle, 2 9F sheath, 1 7F sheath, and 3 spinal needle). A noncoaxial approach was preferred by 4 investigators (15 %). Two articles (7 %) were not exhaustive in this regard.

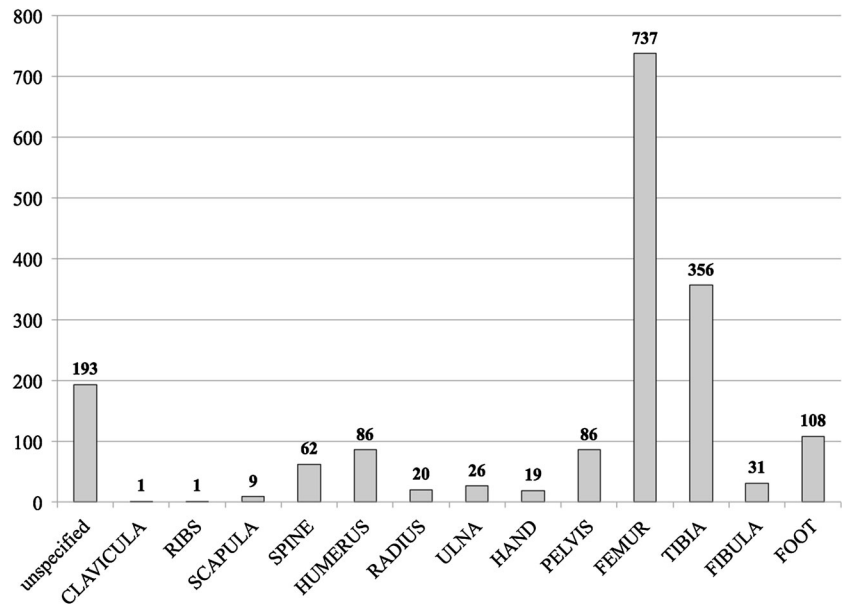
When reported, target ablation temperature in RFA papers ($n_p = 19$) was approximately 90 °C (mean 88.8 °C, $\sigma = 10.3$) with a mean ablation time of 6.8 min ($\sigma = 3.2$, $n_p = 22$), whereas ILA investigators had a mean ablation time of 9 min ($\sigma = 1.4$, $n_p = 4$). No sufficient information was available to express a quantitative reference target for end of ablation during ILA.

Sixteen investigators (59 %) did not specifically prescribe any pain medication immediately after the procedure; 5 (19 %) performed direct or subperiosteal injection of local anesthetic at the end of ablation; and 6 (22 %) recommended generic pain medication for the immediate postinterventional time window.

On average, at least 1-year follow-up data were available for 96 % of treated patients ($\sigma = 0.12$, $n_p = 27$). Sixteen investigators (59 %) required imaging follow-up in symptomatic patients only; 4 (15 %) did not follow-up with imaging or failed to specify; 1 (4 %) recommended follow-up at 60 months; 1 (4 %) performed magnetic resonance imaging (MRI) the day after treatment; 1 (4 %) performed MRI within 1 week; 1 (4 %) performed X-ray and final CT at 24 months; 1 (4 %) performed MRI and scintigraphy at 6 and 12 months; 1 (4 %) performed CT/X-ray at 6 months; and 1 (4 %) performed X-ray during the follow-up period.

Pooled mean clinical success was 96, 95, 94, and 98 % at I, II, III and IV time intervals, respectively ($\sigma_1 = 0.06$,

Fig. 3 Clinical success at 1, 6, 12, and 24 months after thermal ablation



$n_{pI} = 23$; $\sigma_{II} = 0.05$, $n_{pII} = 24$; $\sigma_{III} = 0.06$, $n_{pIII} = 26$; and $\sigma_{IV} = 0.06$, $n_{pIV} = 17$) (Figs. 4, 5). Reinterventions contemplated numbered 92 (5.2 %, mean 3.5, $\sigma = 4.2$, $n_p = 27$). Incomplete treatments numbered 32 (1.8 %, mean 1.2, $\sigma = 1.7$, $n_p = 27$). Forty-four complications were reported (2.1 %, mean 1.5, $\sigma = 1.5$, $n_p = 27$) as follows: 12 cases of skin burn, 5 cases of muscle burn, 4 cases of infection, 3 cases of nerve lesion, 3 cases of tool breakage, 1 case of fracture, 2 cases of delayed skin healing, 2 cases of hematoma, 2 cases of unreachable target temperature, 1 case of pulmonary aspiration, 1 case of cardiac arrest, and 1 case of thrombophlebitis.

Recurrences were reported in 86 patients (4.9 %, mean 3.2, $\sigma = 4.5$, $n_p = 27$). Because not all investigators reported when the recurrence happened, it was not possible to correlate recurrences over time. Twenty patients underwent surgery during the follow-up period (1 %, mean 0.7, $\sigma = 1$, $n_p = 27$), due to pain recurrence or a procedure-related complication.

After qualitative assessment of the investigators' considerations in the discussion sections, we quantified them as follows: 6 (22 %) investigators suggested multiple ablations with needle repositioning for large OOs; 4 (15 %) identified prolonged heating at sustained temperature as a relevant factor to prevent recurrences; 2 (7 %) suggested that no weight-bearing should be allowed after the procedure, whereas other 2 (7 %) affirmed the opposite; 1 (4 %) highlighted the use of contrast MRI as a tool to predict recurrences and undertake early retreatment; 1 (4 %) suspected that a misjudgment of the nidus on CT can lead to incorrect needle positioning; and 1 (4 %) noted that recurrences are more frequent in young patients. Nine investigators (33 %) did not provide relevant considerations regarding the causes of pain recurrence.

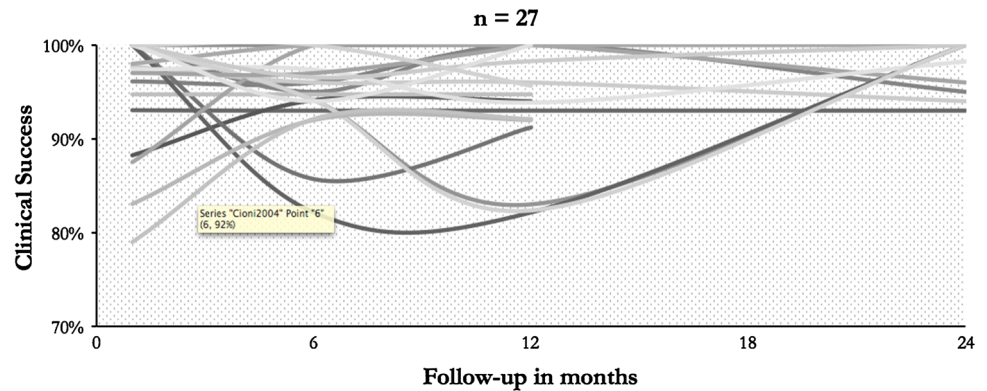
#	Ref.	Author	1m	6m	12m	24m	Sparkline
1	(15)	Earhart J	100%	100%	100%	100%	
2	(12)	Rimondi E			96%		
2(a)	(12)	Rimondi E			79%		
2(b)	(12)	Rimondi E			98%		
3	(8)	Rehnitz C	96%	96%	100%	100%	
4	(11)	Neumann D	100%	100%	100%	100%	
5	(19)	Al-Omari MH	93%	93%	93%	93%	
6	(20)	Daniilidis K	100%	100%	100%	100%	
7	(13)	Mahnken AH	100%	95%	100%	95%	
8	(21)	Miyazaki M	88%	94%	94%		
9	(22)	Mahnken AH	100%	94%	83%	100%	
10	(9)	Roqueplan F	98%	96%	96%	94%	
11	(23)	Beccè F	100%	86%	91%		
12	(24)	Hoffmann RT	95%	95%	95%		
13	(16)	Akhlaghpour S	100%	100%	100%		
14	(25)	Sung KS	100%	82%	82%	100%	
15	(26)	Vanderschueren GM,	88%	100%	100%	96%	
16	(27)	Gangi A,	97%	97%	94%	98%	
17	(28)	Peyscr A,	98%	100%	100%	100%	
18	(29)	Gebauer B,	100%	94%	82%	100%	
19	(10)	Mahnken AH,	83%	92%	92%		
20	(30)	Martel J,	97%	97%	100%		
21	(31)	Cioni R	79%	92%	92%		
22	(14)	Rosenthal DI				89%	
23	(32)	Lindner NJ	100%	97%	98%	100%	
24	(33)	Woertler K,	100%	94%	100%		
25	(34)	Witt JD	100%	100%	96%		
26	(35)	Barei DP			91%		
27	(1)	Rosenthal DI				77%	

Fig. 4 Trends of clinical success during 24-month follow-up

Risk of bias assessment resulted in 6 of 6-star scores for 25 of 27 articles (Table 3) according to the NOS, whereas 2 articles were given 5 of 6 stars (overall mean = 5.93 stars). No papers were excluded after this assessment.

Discussion

PTA is the treatment of choice for OO. RFA is the most adopted technique; ILA is a newer method that has been

Fig. 5 Anatomical localizations**Table 3** Number of stars awarded to each articles per each question after assessment with modified NOS

Article no.	Reference no.	Investigator	Q1	Q2	Q3	Q4	Q5	Q6	Stars
1	[15]	Earhart	A	A	A	B	A	B	6
2(a)	[12]	Rimondi	A	A	A	B	A	B	6
2(b)	[12]	Rimondi	B	A	A	B	A	A	6
3	[8]	Rehnitz	A	A	A	B	A	B	6
4	[11]	Neumann	A	A	A	B	A	A	6
5	[19]	Al-Omari	A	A	A	B	A	A	6
6	[20]	Daniilidis	A	A	A	B	A	A	6
7	[13]	Mahnken	A	A	A	C	A	A	5
8	[21]	Miyazaki	A	A	A	B	A	B	6
9	[22]	Mahnken	A	A	A	B	A	B	6
10	[9]	Roqueplan	A	A	A	B	A	A	6
11	[23]	Becce	A	A	A	B	A	B	6
12	[4]	Hoffmann	A	A	A	B	A	A	6
13	[16]	Akhlaghpoor	A	A	A	B	A	A	6
14	[24]	Sung	A	A	A	B	A	A	6
15	[25]	Vanderschueren	A	A	A	B	A	A	6
16	[26]	Gangi	A	A	A	B	A	A	6
17	[27]	Peyser	A	A	A	B	A	A	6
18	[28]	Gebauer	A	A	A	B	A	B	6
19	[10]	Mahnken	A	A	A	B	A	A	6
20	[29]	Martel	A	A	A	B	A	A	6
21	[30]	Cioni	A	A	A	B	A	A	6
22	[14]	Rosenthal	A	A	A	B	A	A	6
23	[31]	Lindner	A	A	A	B	A	B	6
24	[32]	Woertler	A	A	A	B	A	C	5
25	[33]	Witt	A	A	A	B	A	A	6
26	[34]	Barei	A	A	A	B	A	B	6
27	[1]	Rosenthal	A	A	A	B	A	A	6

5.93

proven as safe and as effective in comparison. Recent papers [6, 7] also show promising results of cryoablation as an alternative approach.

The high rate of clinical success is a distinctive feature of this procedure along with the high incidence of OO in

the young. Our results confirm—on the largest scale and regardless of OO location, PTA technique, or tools used—that PTA is a curative treatment. In fact, among 1,772 patients, we registered a 90–100 % success rate, which was defined as pain disappearance immediately after the

procedure and sustained for over the long term. The complication rate was very low (2 %) and in most cases were minor. Moreover, most investigators (78 %) freed their patients from daily, long-term medication immediately after ablation, whereas the rest recommended it only for the first days after intervention.

However successful, this technique does not adequately treat a small percentage of patients (5 %), who responded differently or not at all. This was confirmed by a transversal presence of recurrences in all articles considered. Even if small, this subgroup of patients is obliged to undergo retreatment, which ultimately multiplies the risk of complications. Furthermore, some may opt for surgery and thus not profit from the advantages of the percutaneous approach. This was true for 20 patients in our review, who needed surgery first due to pain recurrence and secondly due to a procedure-related complication.

Are Recurrences in Fact Incomplete Treatments?

Of 5 % of nonresponding patients, only 1.8 % underwent an unsatisfactory procedure. Some investigators may have not investigated adequately the cause of a recurrence; thus, it is reasonable to deem this gap as “underestimated.” In this regard, at least one follow-up at 12 months with CT or MRI for all patients seems a judicious, if not mandatory, precaution. Instead, 74 % of the investigators did not plan any routine follow-up. Nevertheless, this analysis points to a negative answer to the question. Unfortunately, the differences in study design did not allow for statistical comparison. The present investigators believe that there is still an interest to discern a clearer answer to this question for better understanding the behavior of this benign tumor, such as long-term regrowth after therapy, or to highlight errors in differential diagnosis.

Should the Bar of “Technical Satisfaction” to be Raised?

We searched for adjustments to the ablation technique due to the investigator’s own observations. The heterogeneity of the studies designs did not lead to conclusive results in this matter: Not all of the investigators confronted the issue of recurrences, and it was not possible to extract pertinent assertions from those papers. Still, many considerations can be made. There is agreement that large osteomas tend to recur if not ablated completely [8–12]. To do so, multiple investigators converged on the need of repositioning of the needle and performing multiple coagulations [8–10]. In addition, there seems to be a consensus regarding the importance of confirmation of the needle tip position inside the nidus [11]. In this regard, the majority of investigators

Table 4 Level III evidence suggestions to avoid complications

Investigators	Of total articles (%)	Suggestions
6	2	In presence of a large OO, perform multiple ablations
4	15	Temperature as high as 90 °C and prolonged ablation time is key to true necrosis
2	7	Weight-bearing should be avoided in tensile bones
2	7	Biopsy predicts low recurrence rates...
2	7	... but it should not be performed routinely
2	7	No need for routine activity restriction after procedure
1	4	Positive C-MRI may point to need for early reablation

Table 5 Guidelines for future reporting

Pre/Intraoperative	Postoperative
<i>Imaging of lesion</i>	Imaging of complete ablation Y/N
CT/MR/other	Complications
Outer size/nidus size	VAS at day 1
Location	Postintervention medications
Intra/extra-articular	<i>Follow-up</i>
Cortical/trabecular	VAS at 1, 6, 12, and 24 months
<i>Pain</i>	CT/MR at 12 months; earlier if symptomatic
VAS scale before treatment	Mid and long-term complications
Response to analgesic Y/N	<i>Recurrences</i>
<i>Technique</i>	VAS at time of recurrence
Type of anesthesia	Imaging comparison shows incomplete treatment Y/N
Biopsy Y/N	Chooses surgery Y/N
Temperature (if applicable)	
No. of ablations during the same procedure	
No. of needle positionings	
Overall ablation time	
Outcome	
Primary success: VAS approximately 0 after single ablation	
Secondary success: VAS approximately 0 after repeated ablations	
Recurrence: significant increase in VAS after complete ablation (proven by imaging)	
Incomplete treatment: significant increase in VAS in incomplete ablation (after imaging comparison)	
Patients lost to surgery: patients referred for surgery after first ablation (not due to complications)	

(93 %) used GA in some, if not all, of their procedures. There seems to be agreement that GA is needed to avoid undesired movements during ablation, although LR, CS,

and, less frequently, even local anesthesia, were employed in peripheral locations or collaborative patients. Furthermore, investigators agree that during ablation, a temperature as high approximately 90 °C maintained for more than 6 min is a key to low recurrence rates. In addition, Mahnken and Bruners [13] supported the manner in which contrast-enhanced MRI could be used as a tool to predict early recurrence and thus indicate the need for an early retreatment hypothetically before recurrence.

Finally, complications also contributed slightly to unsatisfactory treatments. Again, neither consensus data nor statistical evidence may be drawn from the investigator's conclusions on which measures, if any, should be undertaken or avoided to lower the risk of complications. For example, we mention two articles that strongly advised against weight-bearing after lower-limb ablation [14, 15], whereas other two articles expressly labeled the same precaution as not needed [16, 17].

Conclusion

The investigators convincingly proved the superiority of thermal ablation for OO compared with other techniques. Thanks to the enormous efficiency of this technique, with success rates solidly close to 100 %, this task was achieved with studies of relatively simple design, mainly focused on technical aspects but in some cases lacking meticulous clinical follow-up. Regrettably, when the technique failed, the interventionists were not able to provide “the best external evidence for a specific clinical question” [18] or adequately investigated the causes of failure.

Considering the 5 % of nonresponding patients, it could be stated that in 95 treated patients, the interventionist will have proven the great benefits of thermal ablation; to the nonresponding 5, he or she will not be able to provide a good explanation for failure.

Implications for Practice

No evidence levels 1 to 2 may be derived from the examined papers regarding the nature of recurrences in OO ablations or the technical adjustments needed to prevent them. The reported indications are to be considered as deriving directly from investigators' experience because the dissimilarity in the design of available clinical trials did not allow for consistent statistical analysis. However, a table of level 3 evidence suggestions for the prevention of recurrences and avoidance of complications after thermal ablation of OO was feasible, is listed in Table 4, and should be used for practice development.

Implications for Research

Future clinical trials for OO ablation should consider reporting essential procedure details and follow-up findings to allow for meta-analysis. The main goal should be clear differentiation between recurrences and incomplete treatments, which may help define the long-term behavior of OO. Recommended standards for future reporting, derived from the present study, are listed in Table 5.

Conflict of interest All authors have nothing to disclose.

References

- Rosenthal D, Hornicek FJ, Wolfe MW, Jennings C, Gebhardt MC, Mankin HJ (1999) Percutaneous radiofrequency coagulation of osteoid osteoma compared with operative treatment. *J Bone Joint Surg Am* 81(3):437–438
- Higgins JPT, Green S (2011) *Cochrane handbook for systematic reviews of interventions* version 5.1.0
- Hozo SP, Djulbegovic B, Hozo I (2005) Estimating the mean and variance from the median, range, and the size of a sample. *BMC Med Res Methodol* 5:13
- Hoffmann R-T, Jakobs TF, Kubisch CH, Trumm CG, Weber C, Duerr H-R et al (2010) Radiofrequency ablation in the treatment of osteoid osteoma-5-year experience. *Eur J Radiol* 73(2):374–379
- Wells GA, Shea B, Connell DO, Peterson J, Welch V, Losos M, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses
- Wu B, Xiao Y-Y, Zhang X, Zhao L, Carrino JA (2011) CT-guided percutaneous cryoablation of osteoid osteoma in children: an initial study. *Skeletal Radiol* 40:1303–1310
- Liu C, Liu X, Zhu B, Yuan H, Han S, Ma Y (2011) CT-guided percutaneous radiofrequency ablation of spinal osteoid osteoma. *Chin Med J* 124(23):4083–4085
- Rehnitz C, Sprengel SD, Lehner B, Ludwig K, Omlor G, Merle C et al (2012) CT-guided radiofrequency ablation of osteoid osteoma and osteoblastoma: clinical success and long-term follow-up in 77 patients. *Eur J Radiol* 81(11):334–3426
- Roqueplan F, Porcher R, Hamzé B, Bousson V, Zouari L, Younan T et al (2010) Long-term results of percutaneous resection and interstitial laser ablation of osteoid osteomas. *Eur Radiol* 20(1):209–217
- Mahnken AH, Tacke JA, Wildberger JE, Günther RW (2006) Radiofrequency ablation of osteoid osteoma: initial results with a bipolar ablation device. *J Vasc Interv Radiol* 17(9):1465–1470
- Neumann D, Berka H, Dorn U, Neureiter D, Thaler C (2012) Follow-up of thirty-three computed-tomography-guided percutaneous radiofrequency thermoablations of osteoid osteoma. *Int Orthop* 36(4):811–815
- Rimondi E, Mavrogenis AF, Rossi G, Ciminari R, Malaguti C, Tranfaglia C et al (2012) Radiofrequency ablation for non-spinal osteoid osteomas in 557 patients. *Eur Radiol* 22(1):181–188
- Mahnken A, Bruners P (2012) Contrast-enhanced MRI predicts local recurrence of osteoid osteoma after radiofrequency ablation. *J Med Imaging Radiat Oncol* 56:617–621
- Rosenthal DI, Hornicek FJ, Torriani M, Gebhardt MC, Mankin HJ (2003) Osteoid osteoma: percutaneous treatment with radiofrequency energy. *Radiology* 229(1):171–175

15. Earhart J, Wellman D, Donaldson J, Chesterton J, King E, Janicki JA (2013) Radiofrequency ablation in the treatment of osteoid osteoma: results and complications. *Pediatr Radiol* 43(7): 814–819
16. Akhlaghpour S, Aziz Ahari A, Arjmand Shabestari A, Alinaghizadeh MR (2010) Radiofrequency ablation of osteoid osteoma in atypical locations: a case series. *Clin Orthop Relat Res* 468(7): 1963–1970
17. Peyser A, Applbaum Y, Khoury A, Liebergall M, Atesok K (2007) Osteoid osteoma: CT-guided radiofrequency ablation using a water-cooled probe. *Ann Surg Oncol* 14(2):591–596
18. Sardanelli F, Hunink MG, Gilbert FJ, Leo G, Krestin GP (2009) Evidence-based radiology: why and how? *Eur Radiol* 20(1):1–15
19. Al-Omari MH, Ata KJ, Al-Muqbel KM, Mohaidat ZM, Haddad WH, Rousan LA (2012) Radiofrequency ablation of osteoid osteoma using tissue impedance as a parameter of osteonecrosis. *J Med Imaging Radiat Oncol* 56(4):384–389
20. Daniilidis K, Martinelli N, Gosheger G, Hoell S, Henrichs M, Vogt B et al (2012) Percutaneous CT-guided radio-frequency ablation of osteoid osteoma of the foot and ankle. *Arch Orthop Trauma Surg* 132(12):1707–1710
21. Miyazaki M, Aoki J, Miyazaki A, Nakajima T, Koyama Y, Shinozaki T et al (2011) Percutaneous radiofrequency ablation of osteoid osteoma using cool-tip electrodes without the cooling system. *Jpn J Radiol* 29(2):138–143
22. Mahnken AH, Bruners P, Delbrück H, Günther RW (2011) Radiofrequency ablation of osteoid osteoma: initial experience with a new monopolar ablation device. *Cardiovasc Intervent Radiol* 34(3):579–584
23. Becce F, Theumann N, Rochette A, Larousserie F, Campagna R, Cherix S et al (2010) Osteoid osteoma and osteoid osteoma-mimicking lesions: biopsy findings, distinctive MDCT features and treatment by radiofrequency ablation. *Eur Radiol* 20(10): 2439–2446
24. Sung K-S, Seo J-G, Shim JS, Lee YS (2009) Computed-tomography-guided percutaneous radiofrequency thermoablation for the treatment of osteoid osteoma-2 to 5 years follow-up. *Int Orthop* 33(1):215–218
25. Vanderschueren GM, Obermann WR, Dijkstra SPD, Taminiou AHM, Bloem JL, Van Erkel AR (2009) Radiofrequency ablation of spinal osteoid osteoma. *Spine (Phila Pa 1976)* 34(9):901–903
26. Gangi A, Alizadeh H, Wong L, Buy X (2007) Osteoid osteoma: percutaneous laser ablation and follow-up in 114 patients. *Radiology* 242(1):293–301
27. Peyser A, Applbaum Y, Simanovsky N, Safran O, Lamdan R (2009) CT-guided radiofrequency ablation of pediatric osteoid osteoma utilizing a water-cooled tip. *Ann Surg Oncol* 16(10): 2856–2861
28. Gebauer B, Tunn P-U, Gaffke G, Melcher I, Felix R, Stroszczyński C (2006) Osteoid osteoma: experience with laser- and radiofrequency-induced ablation. *Cardiovasc Intervent Radiol* 29(2):210–215
29. Martel J, Bueno A, Ortiz E (2005) Percutaneous radiofrequency treatment of osteoid osteoma using cool-tip electrodes. *Eur J Radiol* 56(3):403–408
30. Cioni R, Armillotta N, Bargellini I, Zampa V, Cappelli C, Vagli P et al (2004) CT-guided radiofrequency ablation of osteoid osteoma: long-term results. *Eur Radiol* 14(7):1203–1208
31. Lindner NJ, Ozaki T, Roedl R, Gosheger G, Winkelmann W, Wörtler K (2001) Percutaneous radiofrequency ablation in osteoid osteoma. *J Bone Joint Surg Br* 83(3):391–396
32. Woertler K, Vestring T, Boettner F, Winkelmann W, Heindel W, Lindner N (2001) Osteoid osteoma: CT-guided percutaneous radiofrequency ablation and follow-up in 47 patients. *J Vasc Interv Radiol* 12(6):717–722
33. Witt J, Hall-Craggs M, Ripley P, Cobb J, Bown S (2001) Interstitial laser photocoagulation for the treatment of osteoid osteoma. *J Bone Joint Surg Br* 82(8):1125–1128
34. Barei DP, Moreau G, Scarborough MT, Neel MD (2000) Percutaneous radiofrequency ablation of osteoid osteoma. *Clin Orthop Relat Res* 373:115–124