



# Impact of Magnetic Resonance Imaging (MRI) Findings on Management of Symptomatic Patients Following Radiofrequency Ablation (RFA) of Osteoid Osteoma (OO)

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## Abstract

The purpose of this study is to assess the impact of MRI findings on management of symptomatic patients following RFA of OO. Retrospective review of 43 patients with RFA for OO between June 2010 and June 2017 was performed. Patient, nidus, and ablation data were reviewed. Pre- and 6–8 weeks post-procedural MRI ( $n = 32$ ) were compared for coverage of nidus by ablation zone, bone marrow edema, nidus hyperintensity, and other findings. Baseline pain levels and analgesic use were compared with post-procedural follow-up visit at 6–8 weeks. Three groups of clinical and MRI outcomes of complete (CR), partial (PR), and no response (NR) were defined. A weighted kappa statistic was used to assess for agreement. Clinical responses were CR in 34/43 (79.1%, 95% CI: 64.0–90.0%), PR in 8/43 (18.6%), and NR in 1/43 (2.3%) patients. All 19/32 patients with MRI CR experienced clinical CR. One patient with MRI NR had clinical NR. All 7/32 patients with clinical PR had MRI PR. All 4/43 complications were in MRI PR or NR groups. Substantial agreement was observed between MRI and clinical outcomes (kappa: 0.69, 95% CI: 0.45–0.95). MRI helped determine etiologies in all symptomatic patients and their management ( $n = 8$ ). MRI is recommended for symptomatic patients after ablation.

**Keywords** Osteoid osteoma · Radiofrequency ablation · MRI · Clinical outcomes

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## Introduction

Osteoid osteoma (OO) accounts for 11% of all benign bone tumors affecting males twice than females. It predominantly affects patients in their first and second decades of life. It most commonly affects the diaphyseal or metaphyseal cortex of long bones, particularly in the lower extremities. The classic presentation is a solitary bone lesion causing dull, constant, and achy pain that is worse in supine position and at night and is readily relieved by nonsteroidal anti-inflammatory drugs (NSAIDs) [1].

Osteoid osteoma is commonly diagnosed based on a combination of a characteristic history, physical examination, and imaging findings. Radiographs or computed tomography (CT) evidence of an intracortical nidus with perilesional cortical thickening or MRI findings of a hyperintense, enhancing nidus and extensive perilesional bone marrow edema on T2-weighted sequence are highly suggestive of OO [2]. Multiple treatment modalities exist, including conservative management with chronic use of analgesics, surgical management with en bloc resection or curettage, and image-guided thermal ablation [1].

Multiple image-guided ablative modalities have been utilized for the treatment of OO, including RFA, laser, cryoablation, microwave, and high intensity focused ultrasound (HIFU). Excellent technical success, pain resolution, and low recurrence rates have been reported following ablation for OO [3–8].

Resolution of pain is often considered clinical success. However, when pain persists, determining the cause which is crucial for decision-making is challenging. The purpose of this study is to evaluate the agreement of post-procedural MRI findings with clinical outcomes following ablation of OO specifically for patients who remain symptomatic.

## Materials and Methods

### Patient Selection

Following IRB approval, a retrospective study of patients who underwent RFA for suspected osteoid osteoma between June 2010 and June 2017 was conducted. Study data were captured in a Health Insurance Portability and Accountability Act-compliant database.

Patients were referred for RFA after initial assessment by orthopedic surgeons. All patients underwent pre-procedural radiography, CT, and or MRI to better characterize the lesion and were seen in the outpatient IR clinic. Baseline pain severity as reported by numeric rating scale (NRS) and baseline analgesic daily intake were recorded during clinic visit 1–2 weeks prior to ablation and compared with follow-up visits. Electronic medical records were reviewed for demographics,

clinical data, and technical details related to the RFA procedure. Post-procedural MRI and clinical findings at 6–8 weeks were reviewed for agreement with clinical outcomes. All available data were reviewed for each patient after the 6–8 week visit point (mean follow-up of 6.2 months; range 2–36 months).

Patient demographics and nidus characteristics are recorded in Table 1.

### CT-Guided RFA Procedure

A total of 43 patients underwent 43 CT-guided RFA of the OO by 15 board-certified interventional radiologists with clinical experience in image-guided ablation ranging from 2 to 12 years at the start of this study. All procedures were performed under general anesthesia in a hybrid CT/fluoroscopy procedure room (INTERACT Discovery RT. GE Healthcare, Chalfont St Giles, UK, or ACT/LightSpeed system, GE Healthcare, Chalfont St Giles, UK). All patients received a single prophylactic dose of intravenous cefazolin (ciprofloxacin if allergic to cefazolin) to cover skin flora. Intraprocedural imaging was reviewed by the operating radiologist to identify the best entry point and angle to access the nidus. Grounding pads were placed as per RFA manufacturer's guidelines.

**Table 1** Patient demographics and lesion characteristics ( $n = 43$ )

|                         | <i>N</i> | %     |            |    |
|-------------------------|----------|-------|------------|----|
| Gender                  |          |       |            |    |
| Male                    | 28       | 65.1  |            |    |
| Female                  | 15       | 34.9  |            |    |
| Age (years)             | Mean     | Range |            |    |
|                         | 28.1     | 5–65  |            |    |
| Nidus size (mm)         | Mean     | Range |            |    |
|                         | 6.28     | 3–11  |            |    |
| <i>Prior procedure?</i> | <i>N</i> | %     |            |    |
| Ablation                | 2        | 4.6   |            |    |
| Resection/curettage     | 2        | 4.6   |            |    |
| Lesion location         | <i>N</i> | %     | Laterality |    |
| Lower extremity         | 38       | 88.4  | R          | L  |
| Femur                   | 15       | 34.9  | 6          | 9  |
| Tibia                   | 13       | 30.2  | 10         | 3  |
| Ankle/foot              | 6        | 13.9  | 3          | 3  |
| Acetabulum              | 2        | 4.6   | 0          | 2  |
| Pubic ramus             | 1        | 2.3   | 0          | 1  |
| Fibula                  | 1        | 2.3   | 0          | 2  |
| Upper extremity         | 4        | 9.3   | R          | L  |
| Humerus                 | 3        | 7.0   | 1          | 2  |
| Coracoid                | 1        | 2.3   | 1          | 0  |
| Other                   | 1        | 2.3   | R          | L  |
| L1 vertebral body       | 1        | 2.3   | NA         | NA |

*N* number, *R* right, *L* left, *NA* not applicable

Under maximum sterile precautions, an 11–15G needle was utilized to drill into the nidus. Biopsy samples obtained were sent for surgical pathology assessment [9]. Under CT guidance and utilizing a coaxial technique, a non-tined 7 mm exposed tip applicator (Valleylab, Boulder, CO, USA (8/43 ablations) or Cool-Tip Covidien, Medtronic, Minneapolis, MN, USA) (35/43 ablations) was placed into the nidus. A single applicator was used for most cases (42/43). Ablation parameters included cautery mode for 6 min keeping temperatures at 90–95 °C. Most patients (37/43) received a single ablation, while 7/43 underwent a second tandem ablation at operator's discretion. In selected cases, buffering with saline (hydrodissection) or air (pneumodissection) was performed for protection of the adjacent skin ( $n = 2$ ) or neurovascular structures ( $n = 1$ ) [10]. Continuous intraoperative skin temperature monitoring was done when appropriate. Following the completion of ablation, a final non-contrast-enhanced CT scan of the area was obtained. The average procedure duration was 2.3 h. Technical success was defined by the operator's ability to place the ablation applicator into or abutting the nidus and the ability to complete the ablation with the desired parameters. Patients were moved to the post-anesthesia care unit and received analgesics for expected post-procedural pain. Patients were discharged home after recovery.

### Clinical Response Analysis

Clinical outcome is mainly based on pain assessment by two major indicators of pain severity and analgesic intake. This method is commonly used in palliative ablation of bone metastases, and it has been adopted to OO ablation as well [3, 11]. Pain severity response was divided into three categories: clinical complete response (CR), defined as complete resolution of pre-procedural pain and complete cessation of all analgesics. Clinical partial response (PR) was defined as a minimum decrease of 2 points in the NRS compared with pre-procedural baseline levels or a minimum 25% decrease in analgesic intake (dose or frequency). Clinical no response (NR) was defined as no change or worsening of pain in the NRS or no change or increase in total analgesic intake compared with pre-procedural baseline. The characteristics of pain (biological = tumor = OO vs mechanical = musculoskeletal injury) were also captured from records. Biologic pain with no relationship to physical activity and worsening in supine position is the characteristic presentation of OO. On the other hand, mechanical pain worsens with physical activity.

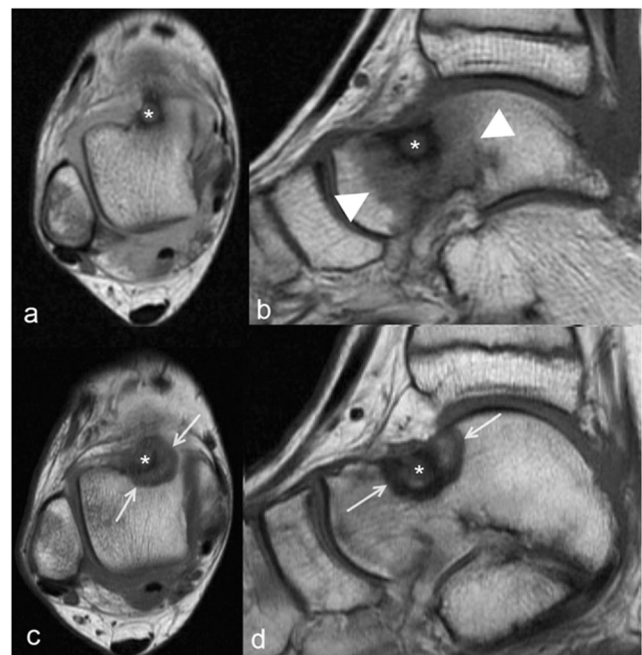
### MRI Response Analysis

A dedicated contrast-enhanced 6–8-week follow-up multiphasic MRI (3.0-T Discovery MR750 GE Healthcare, Milwaukee, WI, USA) was available following 32 ablations. The MRIs were interpreted by 4 musculoskeletal radiologists

with 2–20 years of experience. The MRIs were examined for (1) ablation zone coverage of the nidus on the T1- or T2-weighted post-contrast sequence, (2) nidus hyperintensity on the T2-weighted fat-suppressed sequence, and (3) bone marrow edema on the T2-weighted fat-suppressed sequence. As described by Lee et al., ablation zone was defined as the sharp spherical/ovoid line of hypointensity on T1- or T2-weighted MRI sequences around the site of RF applicator insertion (Fig. 1) [12]. The imaging response was divided into three categories: imaging CR, defined as complete coverage of nidus by ablation zone and complete resolution of nidus hyperintensity and bone marrow/soft tissue edema; imaging PR, defined by complete coverage of nidus by ablation zone with persistent yet reduced bone marrow edema/soft tissue edema or nidus hyperintensity; and imaging NR, defined as nidus being missed by ablation zone regardless of other findings.

### Complications

Complications related to the RFA procedure were recorded and retrospectively evaluated up to 30 days after ablation. The Society of Interventional Radiology (SIR) adverse event classification system was utilized [13].



**Fig. 1** A 15-year-old female with osteoid osteoma of the right talus. (a) Axial and (b) sagittal T1-weighted MR images show the nidus (asterisk) and bone marrow edema (arrowheads). (c and d) Follow-up MRI at 6 weeks clearly show the ablation zone (arrows) completely covering the nidus (asterisk). The bone marrow edema is completely resolved. This patient had clinical CR and imaging CR

## Statistical Analysis

The proportion of complete responders for each outcome was calculated along with the Clopper-Pearson exact 95% confidence interval to account for correlation due to multiple observations per patient. Agreement between imaging response and clinical response was estimated using a Cicchetti-Allison-weighted kappa statistic along with a 95% confidence interval. The weighted kappa assigns less weight to agreement as categories are further apart. All statistical analyses were performed in SAS version 9.4 (SAS Institute Inc., Cary, NC).

## Results

Technical success was achieved in all patients based on operators' opinion at the time of procedure. No ablation was aborted or deemed unsuccessful at the time of procedure. Biopsy samples were diagnostic in 52% of cases for the entire group of operators and 70–80% for those with more expertise [9]. The first imaging assessment of technical success was based on coverage of nidus by ablation zone on MRI obtained 6–8 weeks after ablation.

## Clinical Outcomes

Mean NRS prior to RFA of 7.9/10 with mean analgesic intake of 440 mg/day decreased to mean NRS of 0.7/10 with mean analgesic intake of 28 mg/day after ablation. One patient was lost to follow-up. No statistically significant relationship was found between size of nidus (mean 6.28 mm, range 3–11 mm) and clinical outcomes. Clinical CR was seen following 34/43 (79.1%, 95% CI: 64.0–90.0%) procedures. Eight patients (18.6%) had clinical PR, with partial improvement in pain severity and decrease in analgesic intake. One patient (2.3%) had clinical NR, with pain persistence and no change in

medication intake. Pre-procedural and post-procedural pain score and analgesic use are recorded in Table 2.

## MRI Findings and Clinical Outcomes

Out of 43 patients, 6–8-week post-procedural MRI follow-up was available for 32 (72.7%) patients. The ablation zone fully covered the nidus in 31/32 patients. Imaging CR was seen in 19/32 (59.4%, 95% CI: 40.6–76.3%) MRIs. All 19 patients experienced clinical CR. None of these patients experienced complications related to RFA and required no further ablation or surgical intervention. Imaging PR was seen in 12/32 patients. Of these upon further follow-up, 5 experienced clinical CR and 7 had partial clinical response. Imaging NR was seen in 1 patient who also had clinical NR. Although the operator deemed the ablation technically successful at the time of intervention, upon retrospective review of intraprocedural images with pre- and post-procedural MRIs, the applicator had been placed inferior and medially, missing the nidus which was located at the junction of pubic bone body and superior ramus making it difficult to appreciate on axial intraprocedural CT images. The patient continued to have both mechanical (from focal myonecrosis pectineus muscle) and biologic (from untreated nidus) pain following RFA that increased in severity over a month. Repeat ablation was offered but the patient was lost to follow-up. All complications were found in patients with imaging PR or NR. Five patients with residual bone marrow edema and nidus hyperintensity (imaging PR) had subsequently clinical CR. The imaging findings were resolved in all 5 patients on follow-up MR studies (average 1.2 additional studies, range 1–2 additional studies, follow-up range 8–14 months, average 9.2 months) and none required any further interventions (Fig. 2). MRI was helpful in avoiding unnecessary repeat ablation. Substantial concordance between follow-up MRI and clinical outcomes was found (Table 3) (weighted kappa: 0.696; 95% CI: 0.446–0.946).

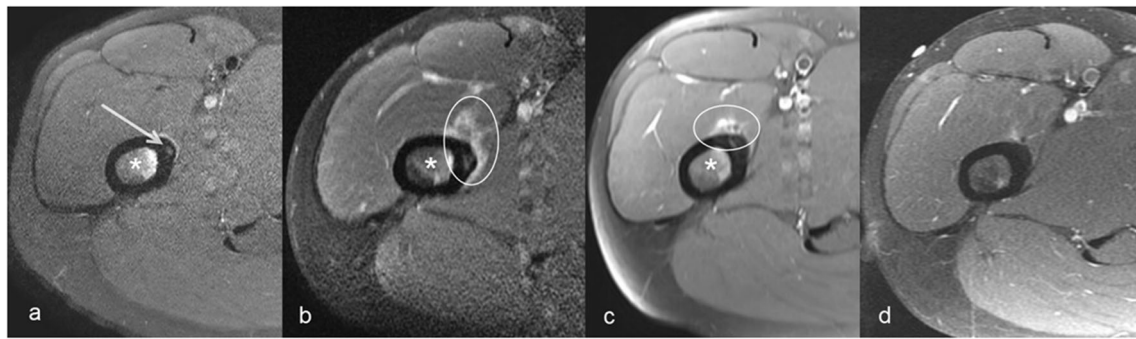
**Table 2** Clinical outcomes ( $n = 43$ )

|                                                                                    | <i>N</i> | %    |
|------------------------------------------------------------------------------------|----------|------|
| Pre-procedural pain severity (7.9/10 NRS)                                          |          |      |
| Severe (7–10/10 NRS)                                                               | 39       | 90.7 |
| Moderate (4–6/10 NRS)                                                              | 3        | 7.0  |
| Mild (1–3/10 NRS)                                                                  | 1        | 2.3  |
| Pre-procedural analgesics use (440 mg/day)                                         |          |      |
| NSAID only                                                                         | 40       | 93.1 |
| Acetaminophen only                                                                 | 2        | 4.6  |
| Combination                                                                        | 1        | 2.3  |
| 6–8 week post-procedural pain severity (0.7/10 NRS) and analgesics use (28 mg/day) |          |      |
| Complete response                                                                  | 34       | 79.1 |
| Partial response                                                                   | 8        | 18.6 |
| No response                                                                        | 1        | 2.3  |

\*One patient was lost to follow-up

*N* number, *NRS* numeric rating scale





**Fig. 2** A 19-year-old male with typical biologic pain of osteoid osteoma: pain with no relationship to physical activity that woke him up from sleep, got worse in supine position, and resolved with nonsteroidal anti-inflammatory pain medications. (a) Axial proton density MR image shows a right proximal femoral nidus (arrow) and adjacent bone marrow edema (asterisk). Contrast-enhanced sequence was not obtained in this study at an outside institution. (b) Contrast-enhanced fat-saturated T1-weighted axial MR image 6 weeks after ablation shows improvement of bone marrow edema (asterisk) and new soft tissue inflammation from

ablation zone in vastus intermedius muscle (circle). Biological pain resolved 2 days after ablation, but patient has mechanical pain that occurs with walking and resolves with resting. (c) Same sequence MR image 7 months after ablation shows further improvement of bone marrow edema (asterisk) and soft tissue inflammation in vastus intermedius muscle (circle). Patient now has pain only with long distance walking. (d) Same sequence MR image 12 months after ablation shows resolution of bone marrow edema and soft tissue inflammation. Patient is asymptomatic

### MRI Findings and Complications

Four patients experienced complications related to the RFA procedure. All had imaging PR or NR on their 6–8-week follow-up MRI. One patient developed osteomyelitis (SIR class D) due to proximity of ablation zone to skin. The 6–8-week MRI demonstrated significant perilesional soft tissue edema extending to the overlying skin. Clinically, the patient presented with purulent discharge from the site of applicator insertion a few weeks after ablation. This patient underwent surgical debridement and intravenous antibiotic treatment and subsequently bone grafting. The three other patients had SIR class A complications (quadriceps hematoma ( $n = 1$ ), focal pectineus myonecrosis ( $n = 1$ ), and temporary skin paresthesia ( $n = 1$ )). All complications were found in patients with imaging PR or NR (Table 3).

### Discussion

Treatment response assessment after ablation of osteoid osteoma is based on clinical symptoms. Very few articles address

correlations of imaging findings and clinical outcomes for OO. Based on Society of Interventional Radiology practice guidelines, the first follow-up visit for an ablated OO is scheduled within 6–8 weeks after ablation with a dedicated MRI examination [14]. At this time, asymptomatic patients are signed off. However, for symptomatic patients, there is no consensus on the method of workup. This is because of paucity of robust studies on correlation of imaging changes after ablation of OO with clinical outcomes. With this regard, there are four issues affecting the available studies:

1. Although coverage of target tumor by ablation zone is considered the fundamental imaging determinant of technical success in ablation of other tumors, it is not commonly used in OO [14]. The vast majority of OO ablations are CT-guided, and CT imaging is not capable of delineating the ablation zone. MRI clearly shows the ablation zone in OO [3, 12] (Fig. 1).
2. There is no consensus on the definition of clinical failure. Most authors consider persistent symptoms as failed treatment of OO. Other than a suboptimally ablated nidus, other

**Table 3** Agreement between MRI and clinical outcomes ( $n = 32$ )

|              |                       | Clinical response     |                     |                |
|--------------|-----------------------|-----------------------|---------------------|----------------|
|              |                       | Complete ( $n = 24$ ) | Partial ( $n = 7$ ) | No ( $n = 1$ ) |
| MRI response | Complete ( $n = 19$ ) | 19                    | 0                   | 0              |
|              | Partial ( $n = 12$ )  | 5                     | 7*                  | 0              |
|              | No ( $n = 1$ )        | 0                     | 0                   | 1*             |

All 19 patients with complete imaging response had complete clinical response. One patient with no imaging response had no clinical response. All 4 patients with complications had partial or no imaging response (\*). Patients with complete clinical response ( $n = 24$ ) do not need MRI evaluation. Only patients with partial ( $n = 7$ ) and no clinical response ( $n = 1$ ) need MRI for evaluation. Considerable agreement is shown between clinical and MRI responses at 6–8 weeks

reasons for persistent symptoms include local tissue injury from ablation intervention and complications such as osteomyelitis.

3. The timing of post ablation imaging studies is widely variable starting from immediate intraprocedural images to studies obtained more than 2 years after ablation!
4. There is no consensus on the imaging findings that correlate best with clinical outcomes.

**Radiography** It remains the best screening test for symptomatic patients to rule out gross complications such as fracture. However, radiographs have no prognostic value for individual patients.

**Computed Tomography** Although gradual decrease in size of nidus and cortical thickening is seen on CT after ablation, no studies have shown its benefit as a prognostic tool in symptomatic patients. It cannot assess bone marrow edema and subtle changes in nidus and surrounding soft tissues. Addition of intravenous contrast does not increase its prognostic value. Studies have shown that CT imaging of OO after ablation cannot identify the activity of nidus and the morphology and calcification of nidus as well as cortical thickening do not correlate with the clinical outcome [4–6].

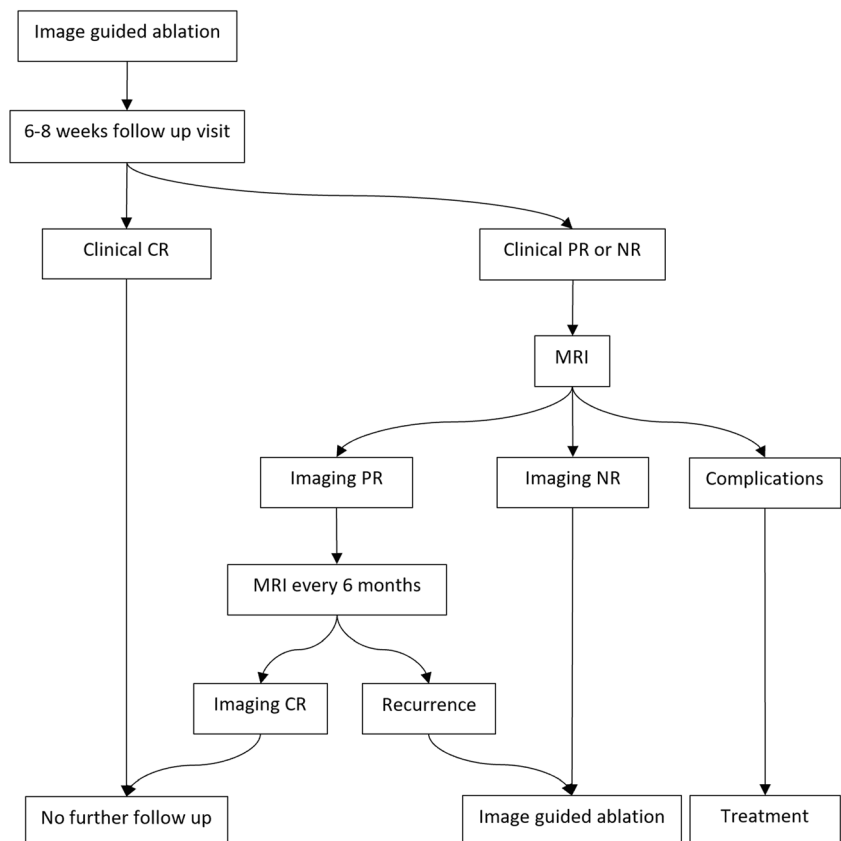
Dual-energy CT (DECT) has been reported to accurately detect bone marrow edema when compared with the MRI as gold standard. However, DECT is not widely available and exposes the patient to potentially high radiation doses [15].

**Magnetic Resonance Imaging** MRI is the most sensitive imaging tool in evaluating the nidus, bone marrow, and soft tissues. However, most studies have design flaws including poor definition of clinical outcomes, lack of consideration of other causes of symptoms like non-target tissue inflammation or complications, binary definition of MR findings without recognition of intermediate steps, poor timing of initial or further follow-up studies, complexity of the method of evaluation of imaging findings, and uniformity of clinical outcomes [4–8].

Napoli et al., in a prospective trial, studied MRI of 45 patients after high intensity focused ultrasound (HIFU) ablation of OO at fixed intervals of 12, 24, and 36 months [3]. They showed that reduction of bone marrow edema and normalization of periosteal and soft tissue findings adjacent to the nidus was 100% in patients with complete clinical response. However, resolution of nidus enhancement was seen in only 76% of patients at 36 months.

The value of enhancement of nidus is questionable especially when complex analyses are taken out of consideration [3–5].

**Fig. 3** Algorithm for response assessment after image guided ablation of osteoid osteoma. Only patients with partial or no clinical response need MRI for evaluation. MRI, magnetic resonance imaging; CR, complete response; PR, partial response; NR, no response



Considerable agreement was shown between clinical outcomes and MRI findings at 6–8 weeks. MRI helped determine etiologies in all symptomatic patients and their management.

Based on results of this work, in this cohort, patients with complete clinical response do not need MRI evaluation at all. Only patients with clinical PR and NR will benefit from MRI. These recommendations are summarized in an algorithm (Fig. 3).

This study has several limitations inherent to the retrospective design. The small sample size limits the capacity of performing multivariable regression analysis and accounting for confounders. Because of individual operator and patient preferences, only 32 patients had follow-up MR exams. The large number of operators created a wide variety of preferences for follow-up imaging modalities including no imaging, radiographs, and CT scans. In addition, MRI assessment was done by 4 different musculoskeletal radiologists with different levels of experience, introducing inter-observer variability. Technical differences between MRI equipment setting could have influenced the degree of bone marrow edema and hyperintensity of the nidus, possibly affecting the individual MRI study when there was small difference between complete and partial response at MRI. Lack of quantitative scale of the signal intensity is intrinsic to MRI in current practice. Larger scale studies would be necessary to validate the concordance between MRI features and clinical response shown in our study.

## Conclusions

Three findings on 6–8-week post-RFA MRI (1) coverage of nidus by ablation zone, (2) resolution of bone marrow edema, and (3) resolution of signal hyperintensity of the nidus demonstrated substantial agreement with clinical outcomes. MRI is indicated for symptomatic patients following RFA of osteoid osteoma.

**Authors' Contribution** Maybody: study conception and design, acquisition of data, analysis and interpretation of data, drafting of manuscript, and critical revision. Soliman: acquisition of data, analysis and interpretation of data, drafting of manuscript, and critical revision. Hwang: study conception and design, analysis and interpretation of data, and critical revision. Gonzalez-Aguirre: drafting of manuscript, and critical revision. Kaye: analysis and interpretation of data, drafting of manuscript, and critical revision. Hsu: analysis and interpretation of data and critical revision. Moskowitz: analysis and interpretation of data and critical revision. Healey: critical revision. Fabbri: critical revision. Santos Martin: study conception and design, drafting of manuscript, and critical revision.

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## Compliance with Ethical Standards

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

**Ethical Approval** Institutional Review Board approval was obtained for this retrospective study.

**Informed Consent** Institutional Review Board approved waiving of obtaining informed consent from individual patients for this retrospective study.

**Consent for Publication** Institutional Review Board approved waiving of obtaining informed consent from individual patients for this retrospective study.

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