Radiofrequency ablation of spinal osteoid osteomas and osteoblastomas: clinical success and technical advances for protecting adjacent neural elements

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Aims and objectives

Osteoid osteoma (OO) is a benign bone tumour of childhood and adolescence [1-2]. Ten percent of all osteoid osteomas are located in the spine, mainly in posterior elements of the lumbar and thoracic vertebral column (Fig. 1 on page 4). OO larger than 15 mm is denominated osteoblastoma (OB) [3]. OB is four times less frequent than OO and often forms a more expansive and less sclerotic lesion and might exhibit a more aggressive imaging and histological pattern [4].

Fig. 1: Imaging characteristics of spinal osteoid osteoma (OO) and osteoblastoma (OB). Typical examples of a spinal OO (left and middle column) and a spinal OB (right column). This entity is frequent: about 13.5% of all benign bone tumours are osteoid osteomas. A lesion larger than 1.5 cm is called OB. The patients are usually younger than 30 years and suffer from "night pain relieved by aspirin" and other nonsteroidal antiinflammatory drugs. The main location is in >50% within the diaphysis of long bones and in 10% within the vertebral column often accompanied by painful scoliosis. Osteoid osteomas show in CT and X-ray a perifocal sclerotic lesion with a central lucency (nidus, marked with open arrows) that is cortically based in 80%. Medullary,
subperiosteal and articular locations also occur. Calcification of the nidus is possible. The nidus is extremely vascular in contrast-enhanced MRI and it is important to identify the nidus as the tumour itself; the surrounding sclerosis and bone marrow oedema pattern (solid arrows in middle and right column) is just reactive. Of note, tumours may have less or no sclerosis if the nidus is located in the marrow or in/adjacent to a joint. In radionuclide bone scans, OO shows intense activity (solid arrow in left column). Key to diagnosis is a sclerotic lesion with a small lucency (nidus) in CT, which has high signal on T2-weighted MRI and a strong contrast-enhancement.

References: Diagnostic and Interventional Radiology, University Hospital Heidelberg - Heidelberg/DE

Therapy is required due to the bone pain independent from physical strain following a nocturnal rhythm. The severe bone pain that typically worsens at night is caused by the excessive production of prostaglandins within the tumour nidus and it responds well to anti-inflammatory drugs [5]. But because long-term treatment with nonsteroidal antiinflammatory drugs is problematic in young patients with regard to potential side effects, open surgical removal of the nidus has been the preferred therapy for OB and until recently, also for spinal OO [6-7].

Although computed tomography (CT)-guided radiofrequency ablation (RFA) is accepted as the gold standard treatment option for OO in the extremities [8-9], this technique is limited in spinal applications because of the risk of thermal damage to adjacent neurovascular structures. Therefore, most authors have excluded OO in critical locations, such as spinal locations or those tumours in proximity to neural structures [10-12].

Thus, the purpose of this study was to assess the clinical success of RFA of spinal OO and OB with the use of dedicated techniques for the protection of neural elements where necessary.
Fig. 1: Imaging characteristics of spinal osteoid osteoma (OO) and osteoblastoma (OB). Typical examples of a spinal OO (left and middle column) and a spinal OB (right column). This entity is frequent: about 13.5% of all benign bone tumours are osteoid osteomas. A lesion larger than 1.5 cm is called OB. The patients are usually younger than 30 years and suffer from "night pain relieved by aspirin" and other nonsteroidal antiinflammatory drugs. The main location is in >50% within the diaphysis of long bones and in 10% within the vertebral column often accompanied by painful scoliosis. Osteoid osteomas show in CT and X-ray a perifocal sclerotic lesion with a central lucency (nidus, marked with open arrows) that is cortically based in 80%. Medullary, subperiosteal and articular locations also occur. Calcification of the nidus is possible. The nidus is extremely vascular in contrast-enhanced MRI and it is important to identify the nidus as the tumour itself; the surrounding sclerosis and bone marrow oedema pattern (solid arrows in middle and right column) is just reactive. Of note, tumours may have less or no sclerosis if the nidus is located in the marrow or in/adjacent to a joint. In radionuclide bone scans, OO shows intense activity (solid arrow in left column). Key to diagnosis is a sclerotic lesion with a small lucency (nidus) in CT, which has high signal on T2-weighted MRI and a strong contrast-enhancement.
Methods and materials

Patient population and ethical policy

Eight patients with spinal OO and two with spinal OB (median age, 22 years; range, 14 - 38 years) were treated with CT-guided RFA since 2009 in our institution. Written informed consent was obtained from all participants after the nature of the procedure had been fully explained. Diagnosis was proven by multi-detector CT, magnetic resonance imaging (MRI), scintigraphic bone scans, and in the two cases of OB using CT-guided biopsy. The lesions were mainly localized in the thoracic vertebral column (n=6), followed by the lumbar spine (n=2) and the sacrum (n=2). All patients underwent a pre-procedural screening that includes the medical history, a physical examination and a basic laboratory analysis. The present study was approved by the institutional review board and performed according to the declaration of Helsinki in the present form.

Treatment protocol and RFA procedural technique

The RFA procedure was performed in the CT room with a multidetector CT under general anaesthesia because nidus penetration is very painful. Sterile methods were used during the whole procedure and the patients were prone positioned on the CT-scanner. Two grounding pads were placed to inhibit the transmission of current through the patient. At the level of the OO multiple thin-section CT images were acquired. Skin access was identified using longitudinally placed cannulas as markers. Skin entry was made after a stab incision and the periosteum was additionally infiltrated with local anaesthetics (2-4 ml of bupivacaine hydrochloride 0.5%) to save narcotics. Procedural techniques included three-dimensional CT-guided access planning in all cases using multiplanar reconstructions in order to define the optimal access path and the number of needle positions needed to cover the whole nidus (Fig. 2 on page 14, Fig. 3 on page 14, Fig. 4 on page 15). The access into the nidus was usually made with a coaxial bone biopsy system including a coaxial manual drilling device. The nidus was then penetrated with the penetration cannula used as a placeholder. After that the radiofrequency electrode was inserted through the cannula and the active tip was placed within the nidus.
Fig. 2: RFA technique of osteoid osteoma within the posterior elements of the vertebral column. Spinal CT-guided RFA can be performed analogue to RFA in peripheral OO without specific protection techniques if the nidus is located within the posterior elements (75% of all spinal OO/OB). Prerequisite is an intact cortical bone as an insulator between the OO and the thecal sac/spinal nerves or a distance OO/critical neural structure > 1 cm [17]. The RFA principle is as follows: The RF-electrode has an active tip, which conducts a current that leads to local ion movement, friction heat and thus to an ablation by coagulation necrosis. The key steps are: 1. optimal access planning (using 3D multiplanar reconstructions), 2. bone puncture, 3. placement of the active tip (we recommend 0.7 or 1.0 cm) into the nidus, 4. ablation time: 400 s at 90° Celsius [10].

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The ablation electrode with two different lengths of the active tip (0.7 cm and 1.0 cm) was used depending on the extent of the nidus. The estimated ablation area was calculated as follows [13]: The maximal size of the treatment zone can be predicted by the following two equations (Fig. 5 on page 16):

(1) longitudinal axis of the treatment zone = 2 x lengths of the bare (i.e. active) tip
(2) transverse axis = 2/3 long axis

![Prediction of the ablation area](image)

- Length of the active tip: \( \sim 0.5 - 2 \text{ cm} \)
- The maximal length of the ablation area can be predicted with the following equation‡:

1. Long axis of the ablation zone = 2 x length of the active tip
2. Transversal axis = 2/3 of the length axis

\[
\Rightarrow \text{oval shape of the ablation area}
\]

‡Pinto CH et al. AJR 2002; 179: 1633-1642

**Fig. 5:** Prediction of the ablation area when using the radiofrequency electrode. We do not use internal cooling to increase the size of the ablation area, because then the ablation area is less predictable and may compromise adjacent structures.

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When the optimal needle position was achieved, the cannula was partially withdrawn to prevent heat propagation along the needle. Then the RF-ablation was started without additional internal cooling using saline solution. The internal cooling has been used in some studies to increase the size of the ablation area but is not necessarily required for OO treatment and the ablation area is less predictable and may compromise adjacent structures [14]. The current was slowly increased until the target temperature of 90° Celsius was reached. The total ablation time was always 400 seconds for each single ablation, regardless the anatomic location and the total number of needle positions [8-9].
In case of OB (with by definition a nidus size of more than 15 mm) a single RF-ablation might be insufficient. Thus, two overlapping RFA needle positions within the nidus in one procedure (double RFA technique; Fig. 6 on page 17) were performed in our two spinal OB cases.

**Fig. 6:** Ablation of osteoblastoma (repeated RFA with partially overlapping treatment zones). Dedicated technique - "double RFA" in an 18-year-old woman with 2.1 cm osteoblastoma in the left pedicle of her fourth thoracic vertebra (open arrow). After CT-guided biopsy, "double RFA" over 400 s at the two positions with 90° C was performed (sagittal CT reformation, right column) with special regard to the distance from the upper and lower neuroforamen and the spinal cord. Pain resolved completely after ablation and no complications occurred.

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Additional thermal protection techniques (Fig. 7 on page 18, Fig. 8 on page 19) were performed in case of missing cortical layer of the tumour with regard to the neuroforamen or the spinal canal and less than 10 mm distance to neural elements (n=3). Thermal protection was achieved by epidural air insufflation, as has been reported before [14], using one or two separate 22-Gauge cannulas in order to yield distance between the
nidus and the spinal cord or nerve and to profit from the insulating effect of the injected air within the adjacent epidural space. The 22-Gauge cannulas were introduced through an interlaminar approach and an epidurogram was obtained after injection of 5 ml of air. Then, thermal ablation was performed for each RFA needle position over 400 s with 90°C Celsius [8-9].

**Fig. 7:** Examples of RF-ablation in proximity to critical neural structures. Dedicated technique - Top row: protection of the thecal sac and the spinal nerves. 22 year-old man with OO in the fourth thoracic vertebra, the cortical coverage to the spinal canal and the neuroforamen is disrupted (arrow in A). Injection of air into the epidural space using a 22G spinal needle. The thecal sac is displaced ventrally and an insulating lamina of air surrounding the nerve is created (arrow in B). Additional perineural air injection to protect the spinal nerve in the neuroforamen (arrow in C). The ablation electrode is placed along the length axis of the oval shaped nidus with the maximum distance to the neuroforamen (arrow in D). Bottom row: thermal protection using injection of air. 17 year-old man with OO in the sacrum with direct contact to the sacral plexus (arrow in A). Bone access via biopsy device, placement directly adjacent to the plexus (B). Injection of air, the plexus (open arrow) is displaced ventrally away from the OO and a lamina of air surrounding the nerve is created functioning as an
insulator (C). Placement of the active tip into the nidus (solid arrow). Ablation without any complications (D).

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In the neuroforamen, we injected a smaller amount of air (Fig. 8 on page 19) and also used this technique to treat a sacral OO nidus adjacent to the sacral plexus nerve (Fig. 7 on page 18).

![Injection of air using a 22 G needle](image1)

**Fig. 8:** Principle of thermal protection before RFA. In case of missing cortical layer of the tumour with regard to the neuroforamen or the spinal canal and less than 10 mm distance to neural elements, thermal protection should be performed prior to.
spinal RFA. By epidural air insufflation, using a separate 22-Gauge cannula, the spinal nerve and the thecal sac were displaced away from the osteoid osteoma in this 38-year-old man, so that the ablation zone was confined to the nidus and did not harm adjacent neural structures. Then, thermal ablation was safely performed without any complications and the typical bone pain resolved completely after thermal ablation.

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In general, patients were discharged within 24 hours after a post-therapeutic ward round including a physical examination.

**Outcome, questionnaire and telephone interview**

Technical success was defined as a completed RFA including placement of the active tip within the nidus, with the nidus border not exceeding the active tip by more than 5 mm, as this distance is considered as effective [15]. Primary clinical success was defined as pain relief after one RFA without the need for pain medication within the following 6 months. Secondary clinical success implies that more than one procedure was necessary. Follow-up MRI examinations were performed 3-6 months later together with a clinical examination. The patients were instructed to contact our department in case of pain recurrence or any other complications. Major complications were defined as prolonged hospitalization or additional treatment unrelated to the tumour [16].

Outcome was qualitatively and quantitatively assessed using a standardized questionnaire which was sent by post to all patients. If patients could not be contacted via post or if answers were equivocal, we again contacted them by telephone to fully obtain questionnaire data. Long-term success was assessed using a questionnaire including visual analogue scales (VAS) regarding the effect of RFA on severity of night pain, pain during all day, and limitations in daily activities as well as sports activities (0-10, with 0 = no pain/limitation up to 10 = maximum or most imaginable pain/limitation). Moreover, other key questions assessed patient satisfaction (from "completely not" over "limited" to "mostly" and "very satisfied"). We defined a reduction of >30% in the VAS score, no pain medication, and a patient satisfaction rated at least "mostly satisfied" as clinical success [8-9]. Failure was defined as lack of significant pain reduction / persisting pain or patient satisfaction rated worse than "mostly satisfied". Further questions quantitatively assessed the time to pain relief and the occurrence of any complications.

**Data analysis and statistics**

Descriptive statistics (mean, standard deviation, median, range) were provided where appropriate. Parametric data (e.g. changes in post-RFA VAS-scores) were tested using
the 2-tailed Student's t-test for all tumours and in the subpopulations OO vs. OB. In all statistical tests, an effect was considered to be statistically significant if the p-value was 0.05 or less. P-values were not adjusted for multiple testing and interpretation of p-values was explorative given the total population of n=10. Data analysis and statistical evaluation were performed with SPSS, version 18 (SPSS Inc., Somers, NY).
Fig. 2: RFA technique of osteoid osteoma within the posterior elements of the vertebral column. Spinal CT-guided RFA can be performed analogue to RFA in peripheral OO without specific protection techniques if the nidus is located within the posterior elements (75% of all spinal OO/OB). Prerequisite is an intact cortical bone as an insulator between the OO and the thecal sac/spinal nerves or a distance OO/critical neural structure > 1 cm [17]. The RFA principle is as follows: The RF-electrode has an active tip, which conducts a current that leads to local ion movement, friction heat and thus to an ablation by coagulation necrosis. The key steps are: 1. optimal access planning (using 3D multiplanar reconstructions), 2. bone puncture, 3. placement of the active tip (we recommend 0.7 or 1.0 cm) into the nidus, 4. ablation time: 400 s at 90° Celsius [10].
**Fig. 3:** RFA of thoracic osteoid osteoma next to large visceral blood vessels. Spinal CT-guided RFA in a 22-year-old woman with night pain responding to salicylates. The OO with 5 mm in diameter is at the anterior and inferior border of the 12th thoracic vertebra adjacent to the inferior vena cava (open arrows). There is perifocal bone marrow oedema (solid arrow). Optimal access planning using 3D multiplanar reconstructions of CT datasets and using the left pedicle as access. The RF-electrode has an active tip of 7 mm to avoid thermal damage of the large vessels of the posterior abdominal wall. Ablation time was 400 s at 90°C. Pain resolved completely after thermal ablation within one day and no complications occurred.

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Fig. 4: Follow-up MRI 2 months after RFA of thoracic osteoid osteoma next to large visceral blood vessels (same patient as in Fig. 3). The ablation area is hypointense in all weightings (solid arrow), the bone marrow oedema visible before RFA has distinctly been resolved. Also, the access path of the RF-electrode is clearly visible (open arrow). Pain vanished completely after thermal ablation within one day and no complications occurred. The patient reported about no limitations in her daily and sports activities.

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**Prediction of the ablation area**

- Length of the active tip: \( \sim 0.5 \text{ – } 2 \text{ cm} \)
- The maximal length of the ablation area can be predicted with the following equation‡:

1. Long axis of the ablation zone = 2 x length of the active tip
2. Transversal axis = 2/3 of the length axis

=> **oval shape of the ablation area**

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Results

• Apart from the typical bone pain, which showed the highest absolute score for the personal limitation, the patients described limitations of sports and daily activities as significant personal limitations (Fig. 9 on page 30).

• Median follow-up time was 31 months. Primary technical and clinical success rate was 10 of 10 patients (100%). No complications were observed. Imaging examples and RFA procedures in spinal OB and OO are given in Fig. 2 on page 25, Fig. 3 on page 25, and Fig. 4 on page 26, as well as in Fig. 6 on page 27, Fig. 7 on page 28, and Fig. 8 on page 29.

Fig. 3: RFA of thoracic osteoid osteoma next to large visceral blood vessels. Spinal CT-guided RFA in a 22-year-old woman with night pain responding to salicylates. The OO with 5 mm in diameter is at the anterior and inferior border of the 12th thoracic vertebra adjacent to the inferior vena cava (open arrows). There is perifocal bone marrow oedema (solid arrow). Optimal access planning using 3D multiplanar
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- The clinical outcome measured with the VAS pain score did not differ between spinal OB and OO. All patients replied in the standardized questionnaire that they were very satisfied with the RFA procedure and all
patients would again choose RFA as first line treatment if they had to decide again. After RFA, the typical bone pain resolved within one week.

- All patients had a clear and persistent pain reduction until the end of follow-up. The mean VAS score for all patients decreased from 8.75 ± 1.50 to 0.57 ± 0.98 both for severity of night pain and for severity of pain during all day (p=0.003). Also, the mean VAS score for all patients decreased from 6.25 ± 4.79 to 0.71 ± 1.89 for limitations in daily activities (p=0.046) and from 7.00 ± 4.76 to 0.71 ± 1.89 for limitations in sports activities (p=0.039). Bar diagrams illustrating the pain level at first presentation and the decrease in pain and limitations after RFA are given in Fig. 9 on page 30.

**Fig. 9:** Bar diagrams illustrating the decrease in pain and limitations after RFA. Illustrated are the values of the visual analogue scale (VAS) regarding the effect of RFA on severity of night pain, pain during all day, and limitations in daily activities as well as sports activities of the patients, which was assessed using a standardized questionnaire.

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Conclusion

RFA, using optimized treatment planning, is an efficient method to treat spinal OO and OB. Table 1 on page 34 gives a summary of our tips and recommendations to perform spinal RFA.

Table 1: Summary of tips and recommendations to perform spinal RFA

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect</th>
<th>Injection of air or CO₂ (about 5 ml) using a 22 G needle in the perineural or epidural space (in case of disruption of the cortical coverage and/or distance &lt; 1 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustment of the access angle in all dimensions with regard to the oval shape of the nidus and the shape of the ablation area</td>
<td>“Double radiofrequency ablation” with different needle positions in large lesions (Fig. 6)</td>
<td></td>
</tr>
<tr>
<td>Optimal size of the ablation area with maximum distance to the critical neurovascular structure (Fig. 2)</td>
<td>Increase in the ablation efficacy in the whole nidus. Coverage of the whole nidus volume</td>
<td>Additional thermal insulation and increasing the distance to the neurovascular structures (Figures 7-8)</td>
</tr>
</tbody>
</table>

Table 1

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The successful treatment of OB requires both a definite histological diagnosis especially when expansive imaging patterns are encountered to rule out malignancy and more than one RFA needle position to cover the entire volume (e.g. double RFA technique).

The treatment of spinal OO and OB depends on the exact localization, because the temperature significantly decreases after more than 1 cm distance from the active tip [17] and the cortical bone has an insulating effect [18]. OO in the vertebral body fulfils these conditions and can be safely treated without protection techniques, when the needle positioning and ablation area are carefully planned. In our opinion, spinal RFA may in particular benefit from thermal protection techniques [14, 19], which can be successfully
used when no cortical bone is preserved and the distance is ≥ 10 mm to neural structures. This is in contrast to reports of other experienced groups, who had treated several spinal OOs but have excluded those critical tumours [7]. In our study, using the aforementioned thermal protection methods, even tumours adjacent to nerve roots or the spinal canal can be treated safely and with very good clinical success.

Thus, also for spinal OO and OB RFA should be regarded as first line therapy, so that open surgical excision of spinal OO and OB will be less needed. Spinal OO and OB surgery has several drawbacks. Besides relapse rates of 4.5-25% [7-8], removal of large osseous parts necessitating augmentation, instability secondary to resection of posterior elements, spinal cord or nerve injury have been reported [20].

**Limitations**

Our study design with RFA as single therapy is a limitation. Success rates were compared with reports on other procedures, while a prospective comparison of RFA with other promising techniques like interstitial laser ablation or microwave ablation would be desirable. Another limitation is the lack of histological tumour verification in case of OO, but we share the prevailing opinion that a histological confirmation is not necessary in the typical constellation of OO. We recommend biopsy, however, in equivocal cases including expansive OB.

In summary, RFA is an efficient method to treat spinal OO and OB and thus should be regarded as first line therapy, even if the tumour is adjacent to neural elements.
Table 1: Summary of tips and recommendations to perform spinal RFA

<table>
<thead>
<tr>
<th>Action</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustment of the access angle in all dimensions with regard to the</td>
<td>Optimal size of the ablation area with maximum distance to the critical</td>
</tr>
<tr>
<td>oval shape of the nidus and the shape of the ablation area</td>
<td>neurovascular structure (Fig. 2)</td>
</tr>
<tr>
<td>&quot;Double radiofrequency ablation&quot; with different needle positions in</td>
<td>Increase in the ablation efficacy in the whole nidus. Coverage of the</td>
</tr>
<tr>
<td>large lesions (Fig. 6)</td>
<td>whole nidus volume</td>
</tr>
<tr>
<td>Injection of air or CO₂ (about 5 ml) using a 22 G needle in the</td>
<td>Additional thermal insulation and increasing the distance to the</td>
</tr>
<tr>
<td>perineural or epidural space (in case of disruption of the cortical</td>
<td>neurovascular structures (Figures 7-8)</td>
</tr>
<tr>
<td>coverage and/or distance &lt; 1 cm)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1

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References


