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ORIGINAL ARTICLE RADIOLOGY

Uncooled microwave ablation of osteoid osteoma: New approaches to an old problem

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ABSTRACT

OBJECTIVE: This study aims to evaluate the technical and clinical success of uncooled microwave ablation (MWA) in the treatment of osteoid osteoma with two-dimensional fluoroscopy guidance in the operating room.

METHODS: The clinical and imaging data of 9 patients were retrospectively evaluated. Mean patient age was 14.55 years. The mean size and volume of the lesions were 17.2 × 10.8 × 8.0 mm and the mean nidus size was 6.86±2.05 mm on computed tomography. MWA was performed with uncooled probe in operating room and in sterile conditions. Numerical pain score was recorded before the procedure, the day after, and at 1, 3 months after the procedure.

RESULTS: Clinical and technical success was achieved in 100% of patients. The mean volume of MWA-induced necrosis was 20.8 × 12.8 × 10.7 mm, peripheral scar thickness was 3.5±0.75 mm, and none of the patients had nidus enhancement on first month follow-up magnetic resonance imaging. Fluoroscopic guidance was conducted under digital c-arm. Patients received four to 12 spot films (mean: 6.6 kVp, 2.66 mAs) over the lower extremity. Mean radiation exposure to the skin due to imaging was 0.02 mGy per patient per procedure. The dose area product-the total amount of radiation deliverable to the patient was 0.75±0.32 Gy.cm^2.

CONCLUSION: This study demonstrated the effectiveness and the safety of the uncooled MWA in osteoid osteoma. The technique may effectively be used in operating room under c-arm fluoroscopy. Such hybrid approach may ensure sterility, anesthetic safety, and lower radiation dose to patients.

Keywords: Bone neoplasms; child; interventional; microwaves/therapeutic use; osteoma osteoid; radiography.

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Osteoid osteomas (OO) are solitary benign tumors that are usually located in long tubular bones of the lower limbs [1]. They generally present with severe nocturnal pain and may occasionally cause growth disturbances, and therefore require prompt diagnosis and treatment [2]. A typical osteoid osteoma consists of a small nidus with occasional calcification and a dense sclerotic reactive zone surrounding the nidus [3]. Dense sclerosis may obscure the visibility small niduses on radiographic images [4]. Computed tomography is superior to radiography for the detection and the evaluation of OO because of its multiplanar capability and superior contrast resolution. The modality is not only used in diagnosis but also as a guide in percutaneous thermal ablation. Today these interventional percutaneous techniques are gradually replaced traditional curative surgery. Although the latter technique has a success rate of 90% [5], complications such as fracture, infection, and hematoma with a rate of 20–45% [6] have resulted in a shift to less invasive interventional techniques.

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Radiofrequency ablation (RFA) is the most commonly used and studied modality among several percutaneous ablation techniques [7]. Microwave ablation (MWA) was developed as an alternative technique to RFA with higher clinical success rates [8] but it still necessitates further validation regarding efficacy and safety. Although there is number of published studies in this regard, they are not as numerous as studies on RFA. Moreover, they have all been conducted using high-power water-cooled systems. Although newer low-power systems do not require cooling, they must be clinically validated in terms of efficacy and safety under routine conditions.

Percutaneous ablation techniques are usually performed under conventional Cone Beam Computed Tomography (CT or CBCT) [9]. These modalities are usually located in diagnostic radiology suites and are used for a number of diagnostic studies. The use of the c-arm-guided ablation method may further establish an approach to reduce the radiation dose inherent to CT techniques [10]. This approach has also been clinically validated regarding efficacy and safety.

This retrospective study aimed to evaluate the technical and clinical success of uncooled MWA with two-dimensional c-arm guidance for the treatment of osteoid osteoma.

Highlight key points

- In the treatment of osteoid osteoma, imaging-guided thermal ablation methods have replaced surgical treatment in recent years. MWA method is successfully applied in the curative treatment of these lesions.
- Uncooled MWA systems are relatively new and stand out with their lower costs, smaller sizes, and similar ablation zones at lower powers compared to cooled systems.
- Percutaneous thermal ablation treatments are frequently performed under the guidance of CT and cone-beam CT. In the pediatric patient group, radiation doses become more significant from a radiobiological standpoint. The average exposure of patients is much lower when using fluoroscopy and when only few spot images are taken.

MATERIALS AND METHODS

Patients

The study was approved by the University of Health Sciences Fatih Sultan Mehmet Training and Research Hospital review board [approval no: 17073117_050.06_050.06].The clinical and imaging data of nine patients who were treated with MWA for osteoid osteoma were retrospectively reviewed. The nine patients consisted of five females and four males with clinical findings and imaging evidence of osteoid osteoma; their mean age was 14.55±5.87 [5–22]. Spinal lesions, lesions between the articular surface, and growth plate and lesions that did not possess safe percutaneous access routes were already excluded. These patients were admitted between May 2017 and July 2020. They all had severe pain that was refractory to analgesics and were referred to our department by the department of orthopedics. All patients were radiologically evaluated with CT with/without magnetic resonance imaging (MRI). Lesions were located in the femoral neck (n=3), lesser trochanter (n=2), femoral head (n=1), distal femoral diaphysis (n=1), tibial diaphysis (n=1), and proximal tibial epiphyses (n=1).

Procedure

All patients were hospitalized before the procedure and were followed-up post-procedurally for 24 h. Procedures were performed under general anesthesia in the operating room and in sterile conditions. All procedures were performed by the same two experienced interventional radiologists and one experienced orthopedist. These specialists determined the safest and the shortest route to access the nidus before the procedure by evaluating the patients together with their radiological images. Important guide marks that could be observed fluoroscopically and patient's optimal lying position during the surgery were determined for the detected path. For example, for a nidus in the medial part of the femoral neck, the insertion angle of the guide wire (K wire) was calculated if it were to be introduced from the lateral leg to the trochanter minor in supine position. Guide marks that were determined as described above were noted preoperatively, and using these marks, a guide wire was sent to the nidus under the guidance of the radiological images obtained by digital c-arm fluoroscopy (OEC Brivio 785 Essential, GEHC) (Fig. 1A, B). When it was established that it had reached the nidus upon radiological examination, a path was created with a drill of appropriate caliber over the guide wire. An 18 G uncooled MWA probe (TATO, Terumo) was inserted under fluoroscopic guidance through that path (Fig. 1C). MWA was performed using a 2.45 GHz at 15 watts to reach a temperature up to 110 °C at the tip of the probe. The ablation time was determined according to the manufacturer-provided parameter table. After ablation, the needle was withdrawn and a sterile closure was applied. All patients were monitored postoperatively at the orthopedics ward and were discharged after 24 h.

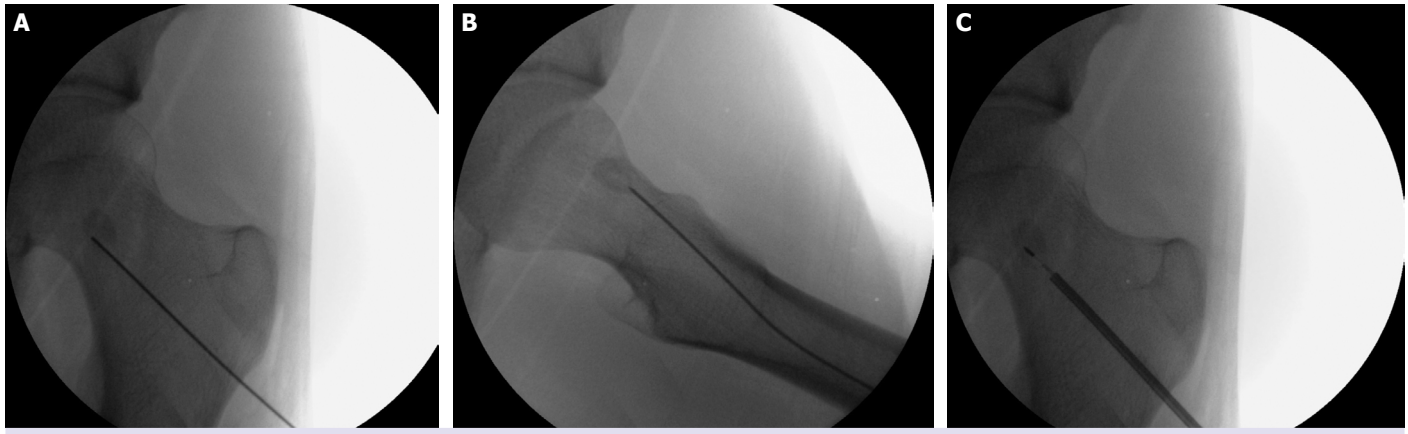

Figure 1. A 22-year-old boy presenting with osteoid osteoma of the femoral head. Positioning the K-wire in a 10 × 13 × 9 mm [0.6 cm3] sized lesion in the left femoral head under fluoroscopic guidance; **(A)** Anteroposterior plane, **(B)** Lateral plane, and **(C)** Uncooled microwave ablation probe placed in the lesion from the trocar with K-wire guidance.

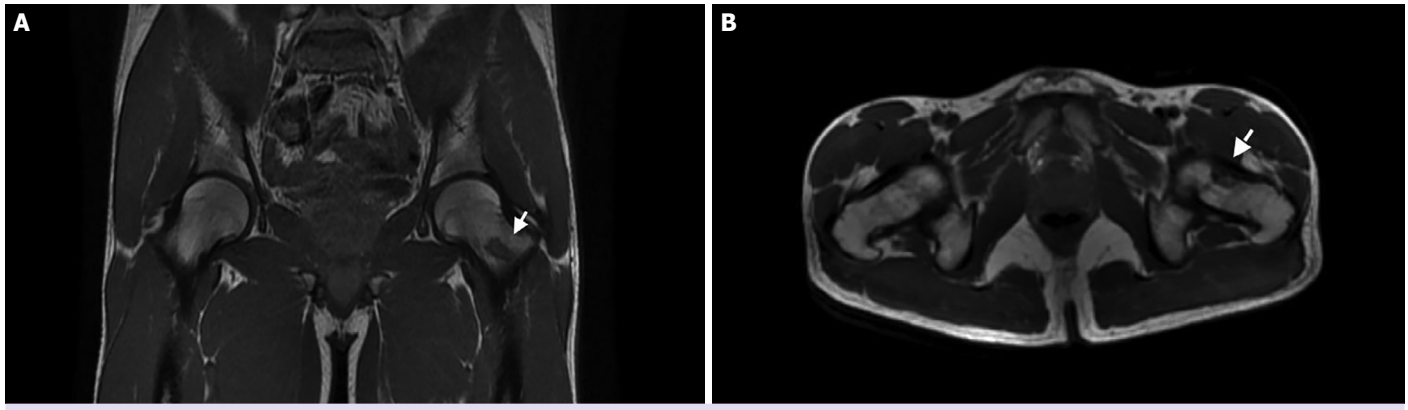

Figure 2. A 22-year-old boy presenting with osteoid osteoma of the femoral head. In magnetic resonance imaging taken at 1-month follow-up of the same patient, coronal **(A)** and axial **(B)** planes in T1-weighted images revealed hypointense regions observed as the necrosis site measured as 15 × 14,8 × 13 mm [1.5 cm3] [arrow]; the necrosis site covers the lesion area as in all other patients.

Follow-up

A scale of 0 to 10 was used to assess the severity of the pain, 0 indicating no pain and 10 indicating the most severe pain as reported by the patient. Pain score was evaluated before the procedure, 1 day after the procedure, and one month after the procedure in all patients for clinical follow-up (Table 1). Contrast-enhanced magnetic resonance imaging (CE-MRI) (Optima 450 W, GEHC) was performed in all patients to evaluate the ablation bed 1 month postoperatively. Gradient echo T1 weighted images were used to determine the necrosis volume and the thickness of peripheral scar. The necrosis volumes with low signals were measured on the coronal and axial images (Fig. 2A, B). This method was used to measure the success of the procedure and its effectiveness over time. In addition, we considered the contrast enhancement of the nidus as another indicator of MWA's technical success. Technical success was considered as the insertion of the microwave probe at the distal rim of the lesion nidus and a temperature >90 °C at the tip of the probe. Clinical success was defined as complete relief of pain at the end of the first month.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (version 25, IBM, USA). Data were expressed using descriptive statistical methods. Continuous variables were reported as the mean±standard deviation (SD) with range.

Table 1. Patient population and detailed results of microwave ablation procedure

Patient no	Age (years)	Sex	Lesion location	Preprocedural symptom duration (months)	Numerical pain score (at baseline 1st day, 1st month 3rd month postoperatively)	Necrosis area measured in MRI one month postoperatively (cm^3)	Thickness of peripheral scar measured in MRI one month postoperatively (mm)
1	22	F	Distal femoral diaphysis	24	9, 0, 1, 0	0.61	2.5
2	16	F	Proximal tibial epiphysis	12	9, 1, 0, 0	0.67	25
3	10	F	Tibial diaphysis	6	9, 1, 0, 0	0.48	3.0
4	18	M	Femoral neck	18	9, 1, 0, 0	0.4	3.6
5	10	F	Femoral neck	24	10, 0, 0, 0	0.65	3.2
6	17	M	Distal femoral diaphysis	6	7, 1, 0, 0	0.8	4.3
7	22	M	Femoral head	3	9, 2, 1, 0	1.5	3.8
8	11	M	Femoral neck	4	9, 0, 0, 0	1.88	4.6
9	5	F	Femoral neck	8	9,1,0,0	1.03	4

MRI: Magnetic resonance imaging; M: Male; F: Female.

RESULTS

The mean duration of active ablation was 6.11±2.2 min and the power was fixed to 15 watts as defined in the manufacturer-provided table. We achieved 100% technical success during operations with no major or minor complications.

Pre-procedural measurements were performed on CT images. The mean size of the lesions was 17.2 × 10.8 × 8.0 mm, mean volume was 0.85±0.72 (0.44–2.71) cm^3, and the mean size of niduses was 6.86±2.05 (4.1–10.2) mm. MRI examination at first-month follow-up revealed the mean size of necrotic site was 20.8 × 12.8 × 10.7 mm, excluding the peripheric scar that was measured as 3.5±0.75 (2.5–4.6) mm. The mean volume of MWA-induced necrosis was calculated as 1.62±1.03 (0.65–2.80) cm^3. Lesions were hypointense in T1- weighted sequences in all patients and none of the patients had nidus enhancement on follow-up (Table 1).

Mean follow up time was 11.67±8.4 (3–24) months. Mean pre-procedural symptom duration was 11.44±8.4 (range 3–24) months. Mean pre-procedural pain score was 9±0.86 (range: 7–10). Mean pain score was 0.77±0.66 (range: 0–2) on the first day, 0.22±0.44 (range: 0–1) 1 month postoperatively, and 0.11±0.33 (range: 0–1) 3 months postoperatively.

Patients were imaged with a combination of low and high fluoroscopy and digital spot modes at 54 to 56 kVp. The exposure time was 20.32±9.66 sec during a combination of low and high fluoroscopy and digital spot modes. The dose area product-the total amount of radiation deliverable to the patient was 0.75±0.32 $Gy.cm^2$.

DISCUSSION

Although the conventional treatment modality for OO is surgery, it requires longer operating time, longer hospital stay, and has higher cost. The total recovery time is also considerably long and morbidity and complication rates are high. Surgical methods may also cause damage to the physics as well as iatrogenic fracture [11]. Percutaneous thermal ablation is a novel and effective technique to treat OO in the younger population [8, 12]. This technique may be used percutaneously by interventional radiologists in radiology departments and does not require an operating room. As CT-guided RFA is the traditional and most widely used variety of the technique [5, 13], it requires the availability of a CT or a CBCT scanner. These systems are usually located in diagnostic radiology suites where they are used for several diagnostic studies, in which there is often no access to optimal anesthesia. Such units may also be problematic in terms of sterility, as switching between diagnostic and sterile conditions may be time-consuming. In the literature, the disadvan-

tages of the radiology suite-based technique over the operating room technique are mentioned. These are poor sterility, greater radiation exposure, poorer accuracy, and increased intraoperative and post-operative complications [14]. We have adopted a hybrid approach to combine the advantages of both techniques. In this approach, procedures are conducted in an operating room to establish optimal sterility and anesthesia. Operative c-arm fluoroscopy is used to guide the procedure to free CT or CBCT time and to substantially lower radiation dose.

Percutaneous ablations are usually conducted using RFA as described above [7]. In the relevant literature, the efficacy rate of RFA is about 95% and the recurrence rate is about 5% [15, 16]. Recurrence may be related to the use of a single needle, poor centralization, inadequacy of the attained temperature, and the development of high impedance inside the nidus. In RFA, technique probes must be positioned exactly at the center of the nidus because the maximum ablation diameter is 1.5 cm. Precise centralization can only be achieved using a three-dimensional guidance method, which forms the basis of CT usage for guidance. Although this problem may also be overcome by inserting multiple needles [17], such an attempt may significantly increase the procedure time [45–120 min] and cumulative anesthetic dose to the patient [18, 19]. In this regard, MWA provides a better alternative to RFA [8] as it offers a more spherical, more homogeneous, and much larger ablation zone with shorter procedure time [20]. In addition, MWA also has the advantage of being less dependent on electrical conductivity so it allows rapidly rising temperature levels up to 170 °C. Significantly shortened procedure time decreases cumulative anesthetic dose. As MWA can easily provide a 3.3 cm ablation zone in osteoid tissue, there is no need to centrally position the probe in the nidus. This provides a significant benefit in lesions where the nidus cannot be perfectly visualized. These benefits, along with the efficacy and safety of the technique, have been the subject of several scientific studies, although significantly fewer than studies on RFA. In this regard, Rinzler et al. [21] reported the technical feasibility and clinical efficacy of MWA in 24 pediatric patients with osteoid osteoma. They performed the procedure under CBCT and achieved a 100% clinical success rate in the 1st month. Prud'homme et al. [8] investigated the success of MWA by evaluating the size of necrosis and the absence of nidus enhancement on MRI. According to their findings, the procedure achieved a mean ablation area of 23 × 15 × 16 mm. These findings were further supported by a study by Basile et al. [22], in which they reported mean ablation area of 21 × 12 × 14 mm for epiphyseal lesions and the patients' pain scores were resolved in the 1st week until the final follow-up. In the present study, we achieved a mean ablation area of 19.2 × 11.5 × 8.8 mm, excluding the 3.43 mm peripheral scar. Our measurements are only slightly lower than the values reported in the relevant literature, but this is an expected outcome considering the applied power difference between our studies and the ones cited above.

Almost all studies to date have been performed using so called cooled MWA systems which permit the delivery of high power to the tissue [8, 21]. In our study, we used a recently introduced but clinically unvalidated uncooled system. This system implements smaller sized probes at lower cost. These probes operate at significantly lower temperatures and may be preferred when high temperatures are undesired, such as in cases where vulnerable structures such as the thyroid gland are located in close proximity [23]. This system, however, may also be used in osteoid tissue, creating an ablation zone almost similar in size by employing almost a quarter of power, as demonstrated in this study.

We used c-arm fluoroscopy to target the lesion and to verify the probe position relative to the nidus. This limits patient radiation dose to a sub millisievert level. Several researchers have compared the radiation doses of CBCT and conventional CT during RFA and MWA while performing the ablation of OO. Cheng et al. [10] conducted a controlled study where they categorized patients into three groups: Intraoperative three-dimensional cone-beam CT imaging with surgical navigation (446.62 mGy/cm), intraoperative three-dimensional imaging (379.78 mGy/cm), and radiology suite-based CT imaging (1058.83 mGy/cm). Perry et al. [24] performed 25 ablations under fluoroscopic CBCT and 35 ablations under conventional CT. Mean effective radiation dose of CBCT (61.5 mGy/cm) was significantly lower. In the pediatric population, such doses become even more significant from a radiobiological standpoint. In the present study, average exposure of patients was much lower than the cited studies due to the use of c-arm and taking only few spot images.

This study has some limitations. It was retrospective in nature and there was no control group in terms of guidance or ablation method [i.e., c-arm vs. CT/CBCT or MWA technique [cooled vs. uncooled]]. The number of patients was also low. Our mean follow-up time was 12.75±8.3 months but recurrence may occur in 1.4 years despite successful treatment [15]. These limitations are due to the novelty of the uncooled technique and will be compensated with gradual experience over time.

Conclusion

This study demonstrated the effectiveness and the safety of uncooled MWA in the treatment of osteoid osteoma. The technique may effectively (c-arm vs. CT/CBCT) be used in the operating room with c-arm fluoroscopic guidance. This hybrid approach may ensure lower radiation exposure.

Ethics Committee Approval: The University of Health Sciences Fatih Sultan Mehmet Training and Research Hospital Ethics Committee granted approval for this study (date: 27.10.2020, 2020/11, number: 17073117_050.06_050.06).

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