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REVIEW ARTICLE

Treatment of focal benign lesions of the bone: MRgFUS and RFA

CARLO MASCIOCCHI, MD, FRANCESCO ARRIGONI, MD, ALICE LA MARRA, MD, SILVIA MARIANI, MD, LUIGI ZUGARO, MD and ANTONIO BARILE, MD

Department of Biotechnological and Applied Clinical Sciences, University of L'Aquila, L'Aquila, Province of L'Aquila, Italy

Address correspondence to: Professor Antonio Barile
E-mail: *abarile63@gmail.com*

ABSTRACT

The objective of this study was to evaluate the role of MR-guided focused ultrasound surgery and radiofrequency ablation in the management of bone and soft-tissue lesions. Musculoskeletal interventional radiology represents an interesting option for the treatment of benign bone and soft-tissue lesions to avoid the invasiveness of surgery and related risks. The imaging techniques now available, besides representing an optimal guide, allow control of the temperature reached in the region of interest, avoiding or minimizing damage to the sensitive structures surrounding the lesion.

INTRODUCTION

Interventional radiology (IR) procedures are well established in the treatment of malignant, particularly metastatic, diseases of bone and soft tissues and are exhaustively described in literature.[1–11]

Conversely, benign diseases are still under investigation and, so far, the treatment of only osteoid osteoma has appeared in literature.[12–15] There is scarce literature describing the characteristics and the treatment of benign lesions other than osteoid osteoma,[16] and the studies are usually restricted to a low number of patients.[17–19] Sometimes, the patients are grouped with others presenting more frequent pathologies of other nature.[20] This is probably owing to the scarce experience in the use of IR in this field. Thanks to technological advances, however, IR can represent an interesting minimally invasive solution for the treatment of benign bone and soft-tissue lesions to avoid surgical invasiveness and related complications, especially in case of lesions with low aggressiveness.

Radiofrequency ablation (RFA)[21,22] is a widely tested technique applied in various fields other than musculoskeletal intervention. Usually, a CT-guided procedure is performed, which requires a single-day hospitalization. The procedure is performed employing a fine needle (about 17 G or little more), which causes minimal injury to the healthy tissues encountered when reaching the lesion.

MR-guided ultrasound surgery (MRgFUS),[23,24] whose technical aspects will be discussed later, is a novel technique which, compared with RFA, does not require the use of needles to reach the lesion. The ablation is performed using energy delivered through an ultrasound beam, which, if the procedure is correctly performed, causes insignificant damage to the healthy tissues.

TECHNICAL ASPECTS

MR-guided focused ultrasound surgery

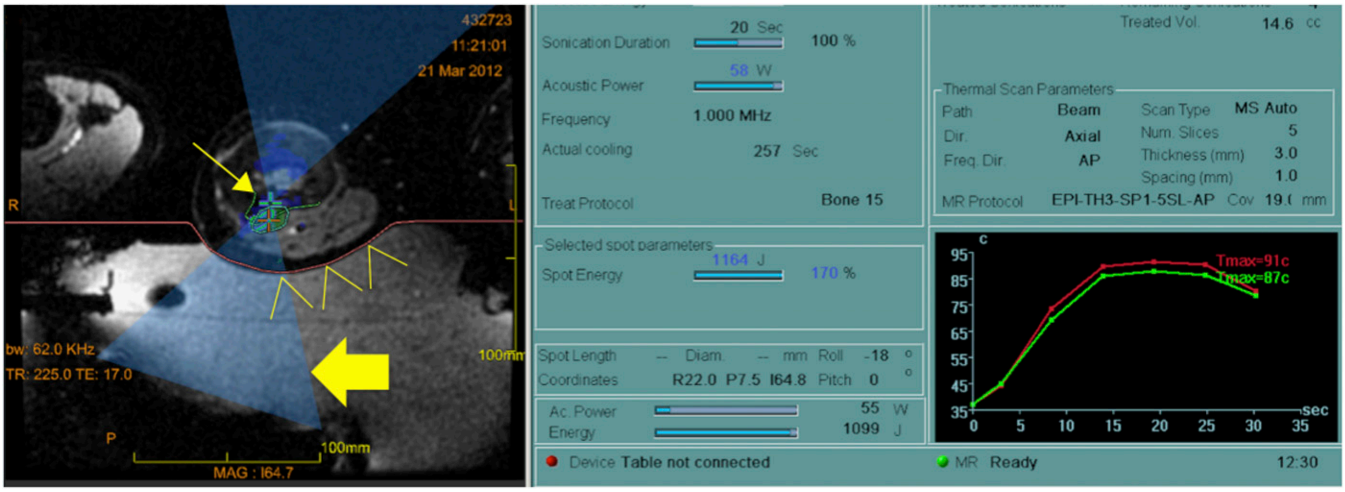
MRgFUS takes advantage of the combination of two physical principles: thermal ablation (high intensity and focused ultrasound beam) and imaging (MRI).

Thermal ablation is obtained by energy delivered on the target tissue with a focused ultrasound beam. The beam causes a temperature increase on a focal point, destroying the target tissue through heat. The temperature can reach 57 °C or more for 1 s (Figure 1), bringing about protein denaturation and consequent coagulative necrosis.

A successful treatment requires that the ultrasound beam reach the target with sufficient energy to cause necrosis.

The accessibility to the lesion is important and all structures interposed between the lesion and the skin surface must permit the transmission of ultrasound without deviation or reflection of the beam (Figure 2). The "acoustic window" has been defined[4,5] as the pathway between the

Figure 1. MR-guided focused ultrasound surgery treatment: the thick arrow is showing the schematic representation of the ultrasonic beam focused on the target lesion (thin arrow); the arrowheads are showing that the skin line is in close contact with the "ultrasound transducer system". On the right is the graphic representation of temperature in the target zone. TE, echo time; TR, repetition time.



skin and the lesion. It must be free of obstacles (metallic devices, air, scars *etc.*). Even bone, which absorbs the ultrasound beam up to 50 times more than soft tissues, can represent an obstacle to the propagation of the beam. Therefore, it can be difficult to reach a lesion deeply located in the bone.

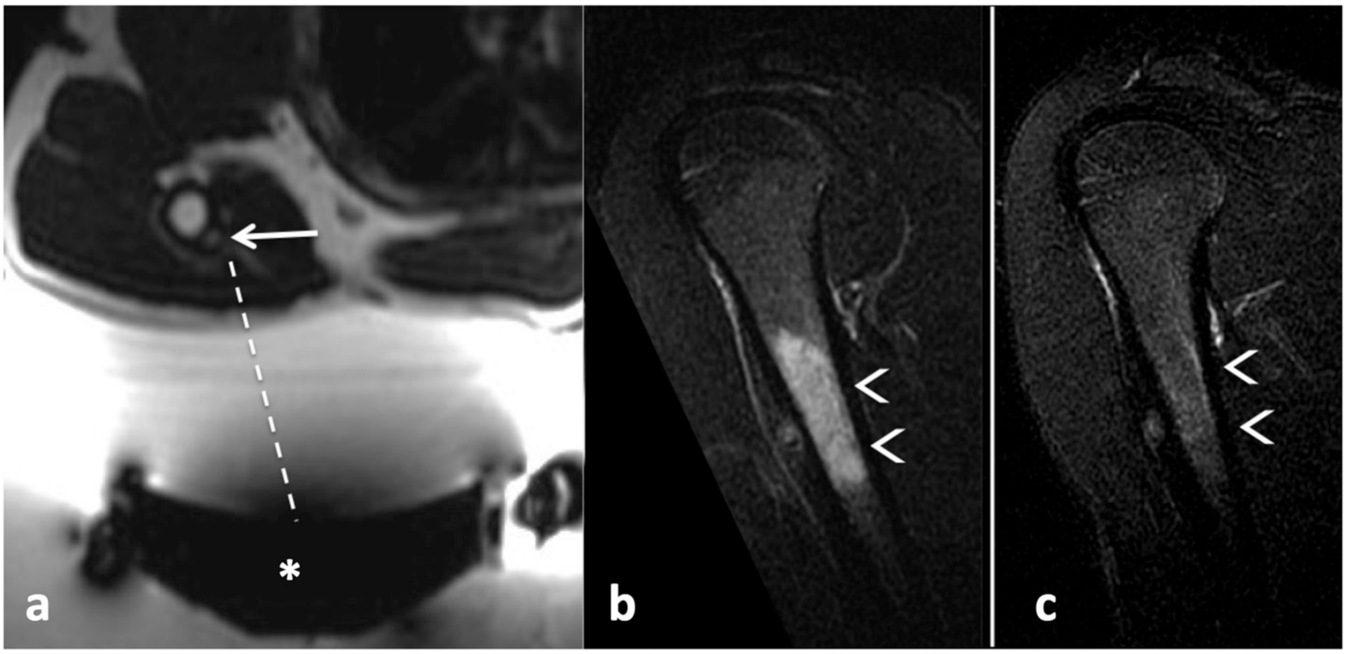
The bone lesions that derive most benefit from MRgFUS are the superficial ones. Their treatment requires a low amount of energy, which is almost completely absorbed by the bone. Conversely, in our experience, lesions located deeper than 12 mm from the cortex were more difficult to treat.

A thick layer of soft tissue can compromise the effectiveness of the ablation, as well. If the distance between the skin surface and the target lesion exceeds 10 cm, the ablation can be compromised.

MRI represents a valid adjunct to the system. Its optimal contrast resolution (with or without administration of contrast medium) allows detection of sensitive adjacent structures.

Using thermometry obtained with the proton resonance frequency (PRF) sequence, it is possible to verify the amount of

Figure 2. Humeral osteoid osteoma: (a) the linear pathway (dotted line) between the lesion (arrow) and the transducer (*) free from anything hindering the proper propagation of the ultrasound beam; (b) bone oedema around the lesion before treatment (arrowheads) and its disappearance 1 year after treatment (c).



energy delivered and the temperature reached, avoiding possible damage to the surrounding structures. This integration with MRI provides an important feedback in real time and without interruptions. Moreover, skin incision, antibiotic prophylaxis and radiation exposure are not required.

During treatment, the patient is positioned on the MRI table, which contains the transducer generating the ultrasound beam. Patient positioning is crucial and attention must be paid to ensure that the skin above the lesion is in close contact with the transducer. The use of mobile transducers makes patient position more comfortable.

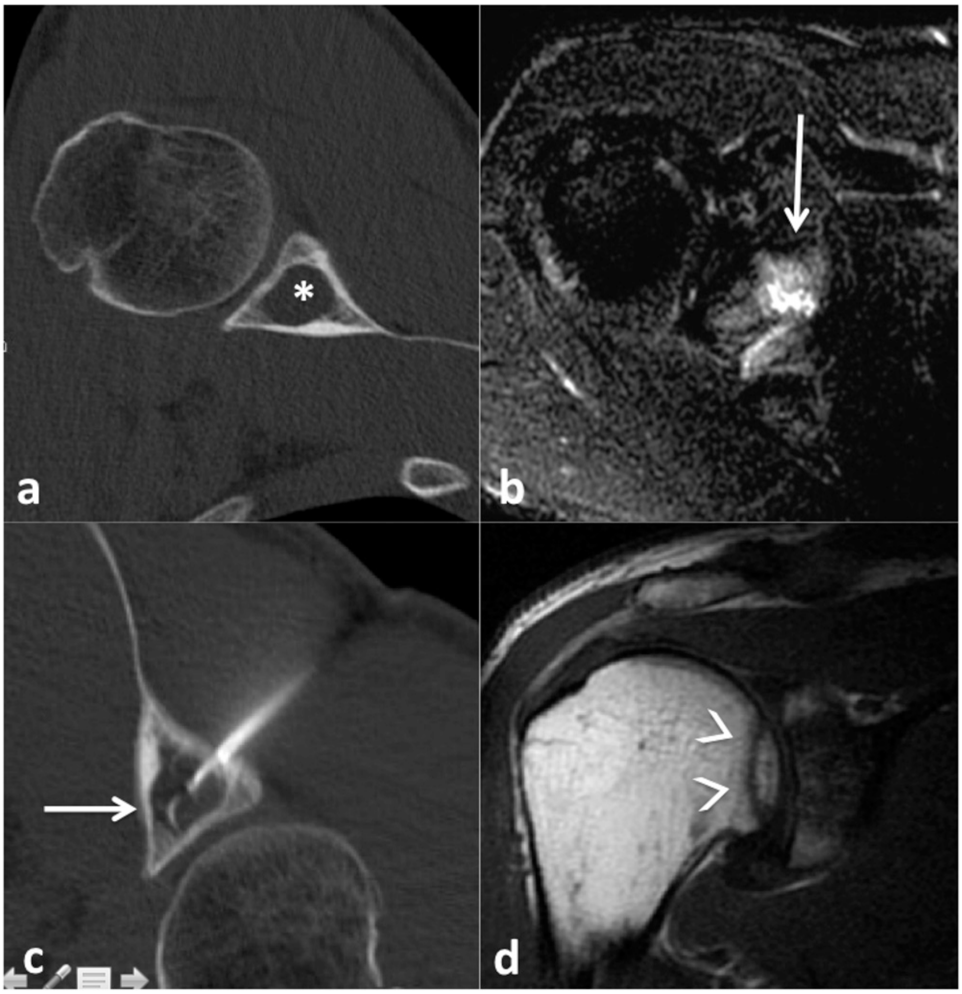
Radiofrequency ablation

The thermal injury caused by RFA is the result of an electrical alternating current flowing through the tissues and producing ionic agitation with consequent resistive heating of the tissues. The electrical current is produced by a system made up of an electrical generator, needle electrode, patient (resistor) and large dispersive electrodes (grounding pad). Owing to the marked difference in size between the surface of the needle electrode and that of the grounding pad, the generated heat concentrates around the needle electrode.

Also in this case, the nature of the thermal damage depends on the temperature reached within the tissue and the duration of heating: an effective ablation can be achieved with a temperature of at least 60 °C. To monitor the effectiveness of the ablation, two different systems are used: temperature control system that monitors the temperature reached and impedance control system that evaluates the impedance reached. The tissue impedance is correlated with the coagulation of the tissue around the electrode and with the effectiveness of the treatment.

RFA is generally performed in combination with CT for a manageable and faster positioning of the needles (it is possible to use more than one needle in case of large lesions). The use of fluoro-CT allows an almost real-time evaluation of the pathway followed by the needles as well as their positioning even under difficult conditions (Figure 3).

Figure 3. (a) A painful bone cyst of the scapula (*) surrounded by bone oedema in the T_2 weighted fatsat image; (b) the same cyst is shown by the arrow; (c) treatment with a radiofrequency ablation needle with an umbrella-shaped array (arrow) ; and (d) 3 months later, the "ring sign" involving the humeral head (arrowheads) is present.



The disadvantages of this technique over MRgFUS, however, are represented by the need to use needles and its related risks (skin and healthy tissue cutting, infection and/or disease spreading), the employment of ionizing radiation and inability to image the treatment area in real time. Thanks to the PRF sequences during MRgFUS, the operator is able to not only verify the temperature of the target lesion, but also monitor the adjacent tissues and avoid damage of sensitive structures. The temperature around the sensitive structures can be evaluated with a "thermocouple", *i.e.* a 22-G needle that can be positioned very close to the sensitive structures, to verify the presence of a critical temperature increase. This manoeuvre requires the positioning of two needles (RFA and thermocouple).

"Hydrodissection" or "air dissection" techniques are also used to save sensitive structures: saline and glucosate solutions, air or CO_2 are injected between the target lesion and the sensitive structures to increase the distance and to avoid thermal injuries.

PATIENT SELECTION CRITERIA AND RATIONALE

The indications for the use of RFA and/or MRgFUS to the best of their potential are described below.

MR-guided focused ultrasound surgery

Owing to its physical properties, the bone absorbs ultrasound more readily than soft tissues, converting mechanical energy into heat. This allows the treatment of bone surface lesions employing a relatively low amount of energy and in short time. Consequently, lesions located on the bone surface are well suited for treatment with MRgFUS.

Surgical sterility of the tissues located superficially to the lesion is guaranteed by the absence of devices of any type to deliver the energy required; the use of needles can lead to a spread of pathological tissue along the pathway, causing relapse. This is particularly true when the lesions are not completely treated. On the other hand, biopsies cannot be performed without the use of needles and this probably represents the main disadvantage compared with RFA. Another advantage offered by MRgFUS is that since it leaves the anatomy of the target region unmodified, there are no preclusions to other treatments, performed with the same or other techniques, even surgical, should they be subsequently deemed necessary.

Radiofrequency ablation

The use of RFA depends on the possibility to reach the lesion with the needle tip.

This technique is preferably employed in case of a deep bone or bone covered by a thick cortex. Sometimes, the target area is reached with a drill. To exploit the advantages offered by RFA, it could be wise to perform a biopsy prior to treatment in each patient.

Compared with MRgFUS, however, RFA does not allow an accurate control of the temperature reached in the region of treatment. Without real-time thermometry, it is not possible to evaluate the surrounding tissues. When introducing the needle, major attention must be paid to the surrounding sensitive structures to avoid mechanical injury. Finally, particular care must be laid to the problem of infections possibly related to the introduction of needles.

DISCUSSION

The attempt to reduce surgical invasiveness has a dual purpose: ethical (less damage to the patient) and economic (reduction of hospitalization time).

The treatment of osteoid osteoma is a typical example of how to obtain excellent clinical results (with success rates ranging from 89% to 100%) using minimally invasive techniques (RFA) that are safe and cost-effective at the same time (single day of hospitalization) and do not present any particular functional limitations after treatment.[5,7,8]

Further, reduction of invasiveness, under equal conditions of efficiency, is obtained using MRgFUS, which does not require skin incisions. The main limitation of using MRgFUS, however, is represented by the position of the lesion: if the lesion is too deeply located in the bone or in the soft tissues, the treatment cannot be carried out.[5]

Current literature describes some experiences in employing RFA to treat musculoskeletal benign lesions, both inflammatory (eosinophilic granuloma of the bone)[19] and of benign tumour type (chondroblastoma and osteoblastoma) (Table 1).[12,13,15]

Our experience includes treatments of different painful bone lesions such as cystic lesions of the bone, areas of intraosseous myxoid degeneration and recurrence of giant-cell tumour (Figure 4), the last one being surgically treated as first therapy. The heterogeneity of the lesions and the aim of this study do not allow going deeper into details of any single treated lesion, but due to the aim of the paper there is not an in depth evaluation of the imaging details; the selection of the patients was based on clinical symptomatology. The presence of bone oedema around the lesion can be considered as the imaging finding to put in relation with clinical symptomatology. We treated 27 painful benign bone lesions (12 lesions with RFA and 15 lesions with MRgFUS), and the follow-up study lasted 3 years.

In keeping with literature, describing positive outcomes in terms of pain relief and lack of recurrence in the long-term follow-up studies (up to 5 years),[25] our experience confirms that both techniques are safe and effective. Of course, an accurate pre-operative assessment of the size and location of the lesion is necessary. Energy must be properly delivered to the lesion, including all the energy within the area of treatment and leaving no possibility of recurrence. In both techniques, pain relief after treatment was considered as the main goal. In particular, 89% of the treated patients referred a marked reduction in painful symptomatology immediately after treatment. This result was considered as successful treatment; in the remaining 11% patients, the painful symptomatology remained after treatment. Retrospectively evaluating the procedure, insufficient delivery of the energy to the lesion was supposed as a possible cause. In these cases, a new treatment is suggested, in particular in case of deep lesions treated with

Table 1. Quoted investigations on the role of interventional radiology of bone lesions

Year	Authors	Type of lesion treated	Technique	Number of patients treated	Number of lesions treated	Follow-up
2007	Catane et al[7]	Bone metastases	MRgFUS	13	15	59 days
2008	Gianfelice et al[8]	Bone metastases	MRgFUS	11	12	3 months
2008	Corby et al[19]	Solitary eosinophilic granuloma of the bone	RFA	2	2	N/A
2008	Lieberman et al[6]	Bone metastases	MRgFUS	31	36	3 months
2009	Rybak et al[18]	Chondroblastoma	RFA	17	17	41 months
2012	Callstrom et al[10]	Bone metastases	Cryoablation	61	69	6 months
2012	Rajalakshmi et al[17]	Chondroblastoma	RFA	3	3	N/A
2013	Napoli et al[9]	Bone metastases	MRgFUS	18	18	<3 months
2013	Napoli et al[14]	Osteoid osteoma	MRgFUS	6	6	6 months
2014	Geiger et al[15]	Osteoid osteoma	MRgFUS	30	30	12 months
2015	Masciocchi et al[5]	Osteoid osteoma	MRgFUS and RFA	15MRgFUS + 15 RFA	15MRgFUS + 15 RFA	<12 months

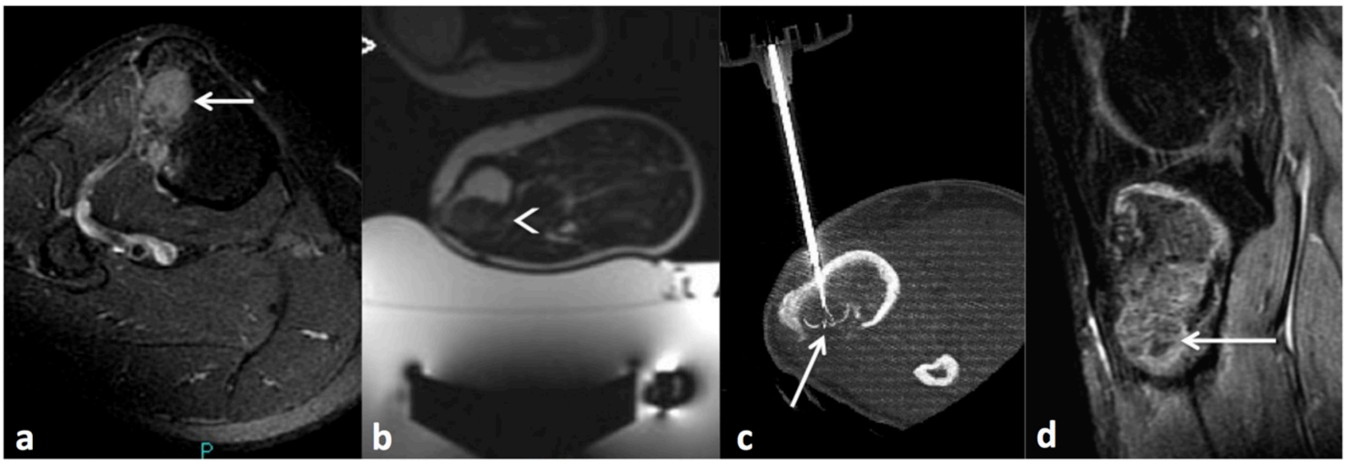
MRgFUS, MR-guided focused ultrasound surgery; N/A, not applicable; RFA, radiofrequency ablation.

MRgFUS: sometimes the beam cannot effectively reach the lesion itself. With an RFA needle, instead, the lesion can be easily reached and ablated. No major complications were recorded in the treatments.

The most common sign found around the lesions is bone oedema, which mainly indicates a reaction of the healthy bone to the growth of the lesion. Its pre-treatment presence is an indication for treatment because the lesion is active and pushes on the surrounding bone. Bone oedema is the cause of pain and its post-treatment disappearance indicates that the lesion is no longer active. In our follow-up, disappearance of bone oedema was observed in all successful treatments.

Another typical sign observed after procedures of thermal ablation (RFA, MRgFUS and cryoablation) is the "halo" or "ring" (Figure 3). This sign is found also when treating the bone[26] and other structures.[27–29] On MRI T_2 weighted sequences, the halo or ring sign generally appears as a round central area characterized by low signal intensity surrounded by a peripheral isohyperintense rim; the CT pattern is very similar and appears as a central hypodense zone surrounded by a rim with higher density.

Figure 4. Recurrence of a giant-cell tumour (of tibia) after surgery: (a) contrast enhancement (arrow); (b) treatment of the recurrence with MR-guided focused ultrasound surgery (lesion is shown by the arrowhead) and (c) radiofrequency ablation (RFA) by means of an RFA needle with an umbrella-shaped array (arrow); and (d) evidence of necrotic area caused by the combined treatments in contrast-enhanced study.



Although the value and meaning of this sign are still under investigation, the central part is probably the result of ablation (*i.e.* the necrotic area, rich in adipose tissue) and the surrounding zone, included in the peripheral rim, is the result of a sub-lethal thermal injury; in fact, the hyperintense rim indicates the presence of a reactive interface between the ablated region and the healthy tissue. At follow-up, the extension of this zone must be carefully evaluated to assess the presence of thermal injury of the tissues close to the lesion treated. This is of particular importance when lesions are treated close to the joints or other sensitive structures. With MRgFUS, it is possible to control in real time the temperature reached in the region of interest, in order to avoid or minimize complications. The treatment of lesions close to the joints requires caution in delivering thermal energy because it is possible to cause some injury to the cartilage and to the articular surface, accelerating the arthritic degeneration of the joint; for this purpose, the thermal map obtained through PRF sequences in the MRgFUS system is helpful and should be closely monitored during treatment.

The only valid alternative to these minimally invasive treatments remains surgery, which, however, is not devoid of complications (for example, acceleration of the process of arthritic degeneration), owing to its invasiveness.

REFERENCES

1. Filippiadis DK, Tutton S, Kelekis A. Percutaneous bone lesion ablation. *Radiol Med* 2014; **119**: 462–9. doi: http://dx.doi.org/10.1007/s11547-014-0418-8
2. Palussière J, Pellerin-Guignard A, Descat E, Cornélis F, Dixmérias F. Radiofrequency ablation of bone tumours. *Diagn Interv Imaging* 2012; **93**: 680–4. doi: http://dx.doi.org/10.1016/j.diii.2012.06.008
3. Staso M, Zugaro L, Gravina GL, Bonfili P, Marampon F, Di Nicola L, et al. A feasibility study of percutaneous radiofrequency ablation followed by radiotherapy in the management of painful osteolytic bone metastases. *Eur Radiol* 2011; **21**: 2004–10. doi: http://dx.doi.org/10.1007/s00330-011-2133-3
4. Masciocchi C, Conchiglia A, Gregori LM, Arrigoni F, Zugaro L, Barile A. Critical role of HIFU in musculoskeletal interventions. *Radiol Med* 2014; **119**: 470–5. doi: http://dx.doi.org/10.1007/s11547-014-0414-z
5. Masciocchi C, Zugaro L, Arrigoni F, Gravina GL, Mariani S, La Marra A, et al. Radiofrequency ablation *versus* magnetic resonance guided focused ultrasound surgery for minimally invasive treatment of osteoid osteoma: a propensity score matching study. *Eur Radiol* 2015. Epub ahead of print. doi: http://dx.doi.org/10.1007/s00330-015-4117-7
6. Liberman B, Gianfelice D, Inbar Y, Beck A, Rabin T, Shabshin N, et al. Pain palliation in patients with bone metastases using MR-guided focused ultrasound surgery: a multicenter study. *Ann Surg Oncol* 2009; **16**: 140–6. doi: http://dx.doi.org/10.1245/s10434-008-0011-2
7. Catane R, Beck A, Inbar Y, Rabin T, Shabshin N, Hengst S, et al. MR-guided focused ultrasound surgery (MRgFUS) for the palliation of pain in patients with bone metastases—preliminary clinical experience. *Ann Oncol* 2007; **18**: 163–7. doi: http://dx.doi.org/10.1093/annonc/mdl335
8. Gianfelice D, Gupta C, Kucharczyk W, Bret P, Havill D, Clemons M. Palliative treatment of painful bone metastases with MR imaging—guided focused ultrasound, *Radiology* 2008; **249**: 355–63. doi: http://dx.doi.org/10.1148/radiol.2491071523
9. Napoli A, Anzidei M, Marincola BC, Brachetti G, Noce V, Boni F, et al. MR imaging-guided focused ultrasound for treatment of bone metastasis. *Radiographics* 2013; **33**: 1555–68. doi: http://dx.doi.org/10.1148/rg.336125162
10. Callstrom MR, Dupuy DE, Solomon SB, Beres RA, Littrup PJ, Davis KW, et al. Percutaneous image-guided cryoablation of painful metastases involving bone: multicenter trial. *Cancer* 2012; **119**: 1033–41. doi: http://dx.doi.org/10.1002/cncr.27793
11. Zoccali C, Rossi B, Zoccali G, Barbarino E, Gregori L, Barile A, et al. A new technique for biopsy of soft tissue neoplasms: a preliminary experience using MRI to evaluate bleeding. *Minerva Med* 2015; **106**: 117–20.
12. Rosenthal DI, Hornicek FJ, Torriani M, Gebhardt MC, Mankin HJ. Osteoid osteoma: percutaneous treatment with radiofrequency energy. *Radiology* 2003; **229**: 171–5. doi: http://dx.doi.org/10.1148/radiol.2291021053
13. Rehnitz C, Sprengel SD, Lehner B, Ludwig K, Omlor G, Merle C, et al. CT-guided radiofrequency ablation of osteoid osteoma: correlation of clinical outcome and imaging features. *Diagn Interv Radiol* 2013; **19**: 330–9. doi: http://dx.doi.org/10.5152/dir.2013.096
14. Napoli A, Mastantuono M, Cavallo Marincola B, Anzidei M, Zaccagna F, Moreschini O, et al. Osteoid osteoma: MR-guided focused ultrasound for entirely noninvasive treatment. *Radiology* 2013; **267**: 514–21. doi: http://dx.doi.org/10.1148/radiol.13120873
15. Geiger D, Napoli A, Conchiglia A, Gregori LM, Arrigoni F, Bazzocchi A, et al. MR-guided focused ultrasound (MRgFUS) ablation for the treatment of nonspinal osteoid osteoma: a prospective multicenter evaluation. *J Bone Joint Surg Am* 2014; **96**: 743–51. doi: http://dx.doi.org/10.2106/JBJS.M.00903
16. Thawait SK, Thawait GK, Frassica FJ, Andreisek G, Carrino JA, Chhabra A. A systematic approach to magnetic resonance imaging evaluation of epiphyseal lesions. *Magn Reson Imaging* 2013; **31**: 418–31. doi: http://dx.doi.org/10.1016/j.mri.2012.08.006
17. Rajalakshmi P, Srivastava DN, Rastogi S, Kumar Julka P, Bhatnagar S, Gamanagatti S. Bipolar radiofrequency ablation of tibial-chondroblastomas: a report of three cases. *World J Radiol* 2012; **4**: 335–40. doi: http://dx.doi.org/10.4329/wjr.v4.i7.335
18. Rybak LD, Rosenthal DI, Wittig JC. Chondroblastoma: radiofrequency ablation—alternative to surgical resection in selected cases. *Radiology* 2009; **251**: 599–604. doi: http://dx.doi.org/10.1148/radiol.2512080500
19. Corby RR, Stacy GS, Peabody TD, Dixon LB. Radiofrequency ablation of solitary eosinophilic granuloma of bone. *AJR Am J Roentgenol* 2008; **190**: 1492–4. doi: http://dx.doi.org/10.2214/AJR.07.3415
20. Rehnitz C, Sprengel SD, Lehner B, Ludwig K, Omlor G, Merle C, et al. CT-guided radiofrequency ablation of osteoid osteoma and osteoblastoma: clinical success and long-term follow up in 77 patients. *Eur J Radiol* 2012; **81**: 3426–34. doi: http://dx.doi.org/10.1016/j.ejrad.2012.04.037
21. Tatli S, Tapan U, Morrison PR, Silverman SG. Radiofrequency ablation: technique and clinical applications. *Diagn Interv Radiol* 2012; **18**: 508–16. doi: http://dx.doi.org/10.4261/1305-3825.DIR.5168-11.1
22. Ruiz Santiago F, Castellano García Mdel M, Guzmán Álvarez L, Martínez Montes JL, Ruiz García M, Tristán Fernández JM. Percutaneous treatment of bone tumors by

radiofrequency thermal ablation. *Eur J Radiol* 2011; **77**: 156–63. doi: http://dx.doi.org/10.1016/j.ejrad.2009.06.012

23. Napoli A, Anzidei M, Ciolina F, Marotta E, Cavallo Marincola B, Brachetti G, et al. MR-guided high-intensity focused ultrasound: current status of an emerging technology. *Cardiovasc Intervent Radiol* 2013; **36**: 1190–203. doi: http://dx.doi.org/10.1007/s00270-013-0592-4
24. Schlesinger D, Benedict S, Diederich C, Gedroyc W, Klibanov A, Larner J. MR-guided focused ultrasound surgery, present and future. *Med Phys* 2013; **40**: 080901. doi: http://dx.doi.org/10.1118/1.4811136
25. Hoffmann RT, Jakobs TF, Kubisch CH, Trumm CG, Weber C, Duerr HR, et al. Radiofrequency ablation in the treatment of osteoid osteoma-5-year experience. *Eur J Radiol* 2010; **73**: 374–9. doi: http://dx.doi.org/10.1016/j.ejrad.2008.11.018
26. Fuchs S, Gebauer B, Stelter L, Schäfer ML, Renz DM, Melcher I, et al. Postinterventional MRI findings following MRI-guided laser ablation of osteoid osteoma. *Eur J Radiol* 2014; **83**: 696–702. doi: http://dx.doi.org/10.1016/j.ejrad.2013.12.018
27. Schirmang TC, Mayo-Smith WW, Dupuy DE, Beland MD, Grand DJ. Kidney neoplasms: renal halo sign after percutaneous radiofrequency ablation—incidence and clinical importance in 101 consecutive patients. *Radiology* 2009; **253**: 263–9. doi: http://dx.doi.org/10.1148/radiol.2531082257
28. Wile GE, Leyendecker JR, Krehbiel KA, Dyer RB, Zagoria RJ. CT and MR imaging after imaging-guided thermal ablation of renal neoplasms. *RadioGraphics* 2007; **27**: 325–39; discussion 339–40. doi: http://dx.doi.org/10.1148/rg.272065083
29. Kishi K, Nakamura H, Kobayashi K, Hashimoto T, Hatao H, Oh-ishi S, et al. Percutaneous CT-guided radiofrequency ablation of pulmonary malignant tumors: preliminary report. *Intern Med* 2015; **45**: 65–72. doi:http://dx.doi.org/10.2169/internalmedicine.45.1397