Eur Radiol (2006) 16: 804–810
DOI 10.1007/s00330-005-0022-3

MUSCULOSKELETAL

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Radiofrequency ablation of chondroblastoma using a multi-tined expandable electrode system: initial results

Received: 25 April 2005
Revised: 17 August 2005
Accepted: 26 August 2005
Published online: 3 November 2005

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Abstract The standard treatment for chondroblastoma is surgery, which can be difficult and disabling due to its apo- or epiphyseal location. Radiofrequency (RF) ablation potentially offers a minimally invasive alternative. The often large size of chondroblastomas can make treatment with plain electrode systems difficult or impossible. This article describes the preliminary experience of RF treatment of chondroblastomas with a multi-tined expandable RF electrode system. Four cases of CT guided RF treatment are described. The tumour was successfully treated in all cases. In two cases, complications occurred; infraction of a subarticular chondroblastoma in one case and cartilage and bone damage in the unaffected compartment of a knee joint in the other. Radiofrequency treatment near a joint surface threatens the integrity of cartilage and therefore long-term joint function. In weight-bearing areas, the lack of bone replacement in successfully treated lesions contributes to the risk of mechanical failure. Multi-tined expandable electrode systems allow the treatment of large chondroblastomas. In weight-bearing joints and lesions near to the articular cartilage, there is a risk of cartilage damage and mechanical weakening of the bone. In lesions without these caveats, RF ablation appears promising. The potential risks and benefits need to be evaluated for each case individually.

Keywords Chondroblastoma · Radiofrequency ablation · Treatment planning · Bone neoplasma · Complications

Introduction

Chondroblastoma is a cartilage based lesion usually occurring in teenage patients. Clinically the patients present with pain and sometimes with soft tissue swelling. Epiphyses or apophyses of long bones are normally affected. These lesions do not resolve spontaneously and interventional treatment is required for pain relief and to prevent further growth. Most chondroblastomas are benign but malignant degeneration in long-standing lesions is possible. The established standard treatment is surgical curettage of the lesion with or without bone grafting [1, 2].

The location in either epi- or apophysis and the proximity to the growth plate can make surgical treatment difficult and potentially disabling [1–3]. In addition, local recurrence rates of 8–20% are described in the literature. Particularly large lesions in close proximity to sensitive joint structures can be difficult to eradicate and joint or physeal damage can occur during treatment [2, 4].

An alternative treatment using radiofrequency (RF) ablation was first described in 2001 [5]. The first application seems to have been accidental when a lesion thought to be an osteoid osteoma was treated as such with RF ablation. No complication was encountered and subsequently two further chondroblastomas were successfully treated with a plain RF electrode. In these cases clinical and imaging follow-up of at least 2 years did not reveal any complication.

RF ablation is routine in the treatment of osteoid osteoma and has also gained popularity for the treatment of bone metastases [6–8]. RF ablation treatment is based on the deposition of thermal energy generated by high-frequency electric currents in a lesion [9, 10].

Unipolar and bipolar systems can be used with the unipolar systems being more popular. In bipolar systems the current flows between two electrodes; in unipolar system one electrode is replaced by large surface area grounding plates [9, 10].

For small lesions, single plain electrode systems suffice. The plain electrode systems can be very small allowing for easy access. The size of the treatment area is fairly reproducible and handling is not difficult [9, 10]. For the treatment of larger lesions, multitined expandable electrodes or single-cooled electrodes are advantageous and more effective than multiple applications with a single electrode system as they allow larger areas to be treated confidently [9–11]. Bipolar and cooled electrode systems also allow for the treatment of large volumes. Bipolar and, in particular, cooled electrode systems are quite large in diameter, for bipolar systems the exact positioning of the two poles is important and channelling effects of the RF current can occur [12].

Surgical treatment is potentially disabling. The authors have treated more than 50 osteoid osteomas with RF ablation and have also applied this technique to bone metastases. In these applications it has proved its worth and superiority to open surgery in the right circumstances. RF ablation was seen as having the potential to achieve the same for treatment of chondroblastomas, particularly of lesions that were recurrent or likely to result in poor surgical results. As the lesions were large, a multitined expandable electrode system was used. There is no prior experience published with such a system applied to chondroblastomas and the preliminary results with follow-up after the treatment of four patients are described here.

Materials and methods

Four patients have been treated for biopsy proven chondroblastoma. Patient and treatment details are provided in Table 1, the images are in Figs. 1, 2 and 3.

The patients were initially referred for assessment for RF ablation due to concerns regarding the outcome of surgical treatment for their condition. All patients referred were treated with RF ablation.

All cases were discussed at a multidisciplinary meeting of orthopaedic surgeons, radiologists and pathologists; RF ablation was preferred to surgery to reduce the invasiveness and potential collateral damage of the intervention. Informed consent was obtained. The patients were aware that the proposed treatment was innovative and experimental, and lacking an evidence base. The procedure was planned in advance to ensure treatment of the entire lesion with minimal trauma and collateral damage.

The procedure was performed under general anaesthesia using CT guidance. An orthopaedic surgeon and radiologist were present during the procedure.

Access to the lesions was gained by using a Jamshidi-type trochar set. This was advanced through normal bone

Table 1 Age, sex, location, size, number of RF applications, length of follow up and complications for 4 cases of chondroblastoma treated with radiofrequency ablation with a multi-tined expandable electrode

	Case 1	Case 2	Case 3	Case 4
Age	16	15	15	13
Sex	Female	Male	Male	Male
Location	Left greater tuberosity humerus	Left proximal tibial epiphysis	Right lateral femoral condyle	Left proximal lateral tibial epiphysis
Size	3.6 × 1.7 × 1.8 cm	0.8 × 1.2 × 1.0 cm	2.5 × 4 × 3.7 cm	4.6 × 4.8 × 1.8 cm
Number of positioning/ RF ablations	2	1	4	4
Follow up	1 year, 8 months	1 year	1 year, 10 months	1 year, 8 months
Comments/ complications		Collapse of the tibial plateau	Repeat recurrence after previous surgery (twice) with attempted local resection	Pre-treatment collapse of lateral tibia plateau, post-treatment cartilage defects in the medial tibiofemoral joint and osteochondritis dissecans of medial femoral condyle
Figure	1	2		3

No evidence of recurrence in all cases. Age at the time of RF ablation. Size in AP, lateral, craniocaudal extension

Fig. 1 Case 1: Chondroblastoma left proximal humerus. AP radiograph (**a**), paracoronal T1-weighted (**b**) and STIR (**c**) MR images. Placement of the multi-tined expandable electrode into the lesion from an anterior approach in two sites (**d–e**). Radiographs taken 9 months after the procedure (**f–g**) demonstrate sclerosis in the area of the previously seen chondroblastoma. The patient became and remained asymptomatic immediately after the RF ablation

into the lesion. The trochar used is electrically insulated with a plastic coating. This can increase mechanical resistance when advancing the trochar through dense bone but is necessary to avoid RF application along the length of the trochar. The inner stylet was then removed and a multi-tined expandable RF electrode (RITA Medical Systems, Mountainview, California) was used in all patients with a RITA Model 1500X RF generator (RITA Medical Systems, Mountainview, California, USA). The multi-tined expandable electrode was advanced into the lesion and expanded. The maximum diameter of the system is 4 cm, the diameter is seamlessly adjustable from 0 to 4 cm resulting in a maximal treatment area diameter of 6 cm. The adjustability makes this system very versatile and is the reason why it was chosen. A plain electrode system was also at our disposal.

Needle placement was confirmed with CT and RF current was applied. The system was set to achieve a target temperature of 90°C for 5 min. With the RITA umbrella needle there are seven active elements and six thermal sensors. There are several options for the application of the RF current. The target temperature can be chosen as maximal, minimal or average temperature measured at the thermocouples. The setting chosen was average. After the procedure the patients were observed for one night and discharged the following day.

The patients underwent further follow-up, initially 3 monthly then 6 monthly, on an outpatient basis. The patients were also instructed to contact the surgeon when pain recurred or any other problem related to the treated area arose. When clinical symptoms arose, follow-up imaging was undertaken, depending on the suspected underlying problem with radiographs, CT, MRI or all. In one case (case 1) a follow-up radiograph was taken to confirm absence of radiographic evidence of recurrence in the absence of clinical symptoms.

Results

There was no immediate complication. Access to the lesions with a Jamshidi-type trochar was feasible and

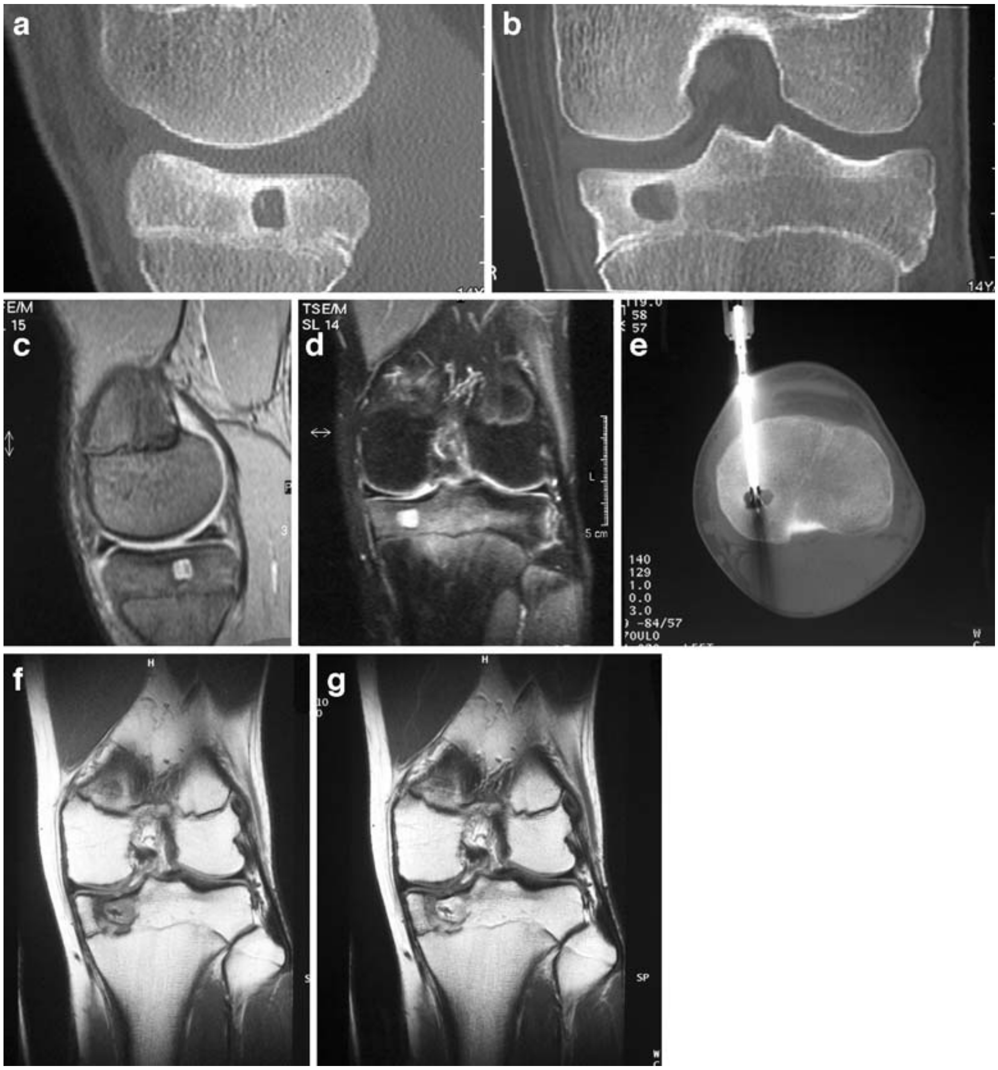

Fig. 2 Case 2: Chondroblastoma left knee, proximal, medial tibial epiphysis. Sagittal (**a**) and coronal (**b**) CT reconstructions and sagittal GRE T2* (**c**) and STIR (**d**) weighted images demonstrate a small lytic bone lesion with central calcification in the medial tibial epiphysis. Treatment CT demonstrates the multi-tined expandable electrode in the lesion (**e**). After recommencing impact sports 7 months after the procedure, the patient developed exercise-related pain. MR imaging demonstrates infraction of the tibial plateau, bone marrow oedema and contrast enhancement of the lesion and adjacent bone marrow: coronal T1-weighted (**f**), coronal T1-weighted after i.v. Gadolinium administration (**g**). The coronal T1-weighted images also show a small bone defect in the cortex of the tibial plateau

largely unproblematic. In one case, damage to the insulating plastic coating to the access trochar was noted, and follow-up imaging demonstrated sclerosis along the needle tract (case 2), presumably due to thermal ablation. The deployment of the umbrella-type RF electrode was achieved in all cases. In small lesions, the umbrella could not be deployed to its maximal diameter but only to the diameter of the lesion (for lesion size see Table 1). With minor manipulation, the multi-tined expandable RF electrode could be deployed even if one of the seven electrodes got stuck. The multi-tined expandable electrode was strong enough to deploy in areas of bone destruction with residual ossified trabecules. With appropriate choice of access paths, it was possible to treat the entire lesion. However, that did require repositioning of the electrode (see Table 1).

Gas formation was seen at target temperatures of 90°C. In three cases minor charring of the electrodes was observed. This is recognizable from blackened and dehydrated coagulated blood. This did not encase the electrodes and affected only a small proportion (<5%) of the surface area of the electrodes.

In one case, temperature inhomogeneities were observed at 80°C minimum and 96°C maximum, resulting in a difference of 20%. There was no evidence of tumour recurrence in the follow-up interval (15, 9, 5 and 15 months).

Complications occurred in two patients (case 2 and 4). In both patients, the lesion was located in the proximal tibia. Patient number 2 (RF ablation of proximal medial tibial epiphysis) was initially completely asymptomatic for 7 months after treatment. After recommencing impact sports, some knee discomfort was noted related to exercise. Follow-up CT and MR imaging demonstrated infraction of the tibial plateau overlying the treatment area. The patient was only symptomatic after impact sports and remained pain-free after abandoning these. In patient number 4 (RF ablation of proximal lateral tibial epiphysis) the tibial plateau had collapsed due to the chondroblastoma prior to RF ablation. About 4 months after the RF ablation, complications oc-

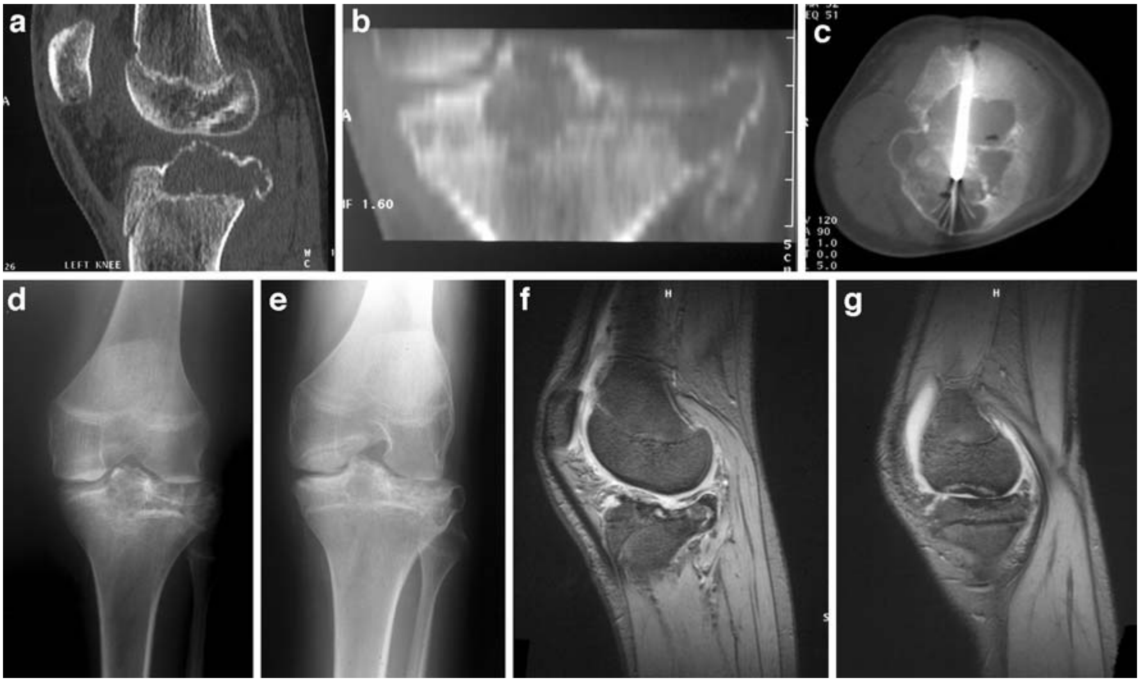

Fig. 3 Case 4: Chondroblastoma proximal left tibial epiphysis. Large expansile lesion as seen on sagittal (**a**) CT reconstructions. There was reluctance to surgically address this lesion due to the potential joint damage. RF treatment was also considered risky. However the tibia plateau then began to collapse (**b**) and RF treatment was performed with RF application in four RF probe locations (**c**). An initial radiograph 2 months after the procedure (**d**) demonstrates the pre-treatment lateral tibial plateau collapse but no other complication. Three months later, sudden pain and decreased ROM of the knee joint occurred. Radiographs demonstrate osteonecrosis of the medial femoral condyle (**e**; contra lateral to the RF treatment). MRI demonstrates collapse of the lateral tibial plateau with preserved cartilage cover (**f**; lesion and treatment side) and chondrolysis, osteonecrosis and osteochondritis dissecans in the medial tibiofemoral joint compartment (**g**)

curred in the medial tibiofemoral joint, which was not affected by the chondroblastoma. MR imaging demonstrated chondrolysis, and osteonecrosis of medial tibia and femur and osteochondritis dissecans of the medial femur condyle developed. The osteochondral fragment was removed arthroscopically. After this the patient became asymptomatic.

Discussion

Radiofrequency ablation of chondroblastomas is a relatively novel way of treatment for this condition. It was first described in 2001 and so far to the authors' knowledge that is the only report [5]. In that study, a single-electrode RF system proven in the treatment of osteoid osteomas was used. While there is substantial experience with such systems as indicated by the high case number treated in published studies [8, 13–17], the treatment of larger lesions is not feasible with it.

The present study presents the first published experience of chondroblastoma treatment with a multi-tined expandable electrode system. There are significant differences between plain and multi-tined expandable electrode systems. To achieve ablation of a lesion, the entire lesion must be in the therapeutic temperature range. In lesions with diameters similar or larger than the treatment area of an RF electrode, this necessitates RF probe repositioning. Overlap of treatment areas must be achieved to ensure treatment success. Plain electrodes can only treat small areas of the lesion at a time, and if the lesion is large (i.e. 4 cm), this would require multiple (dozens) resitings, which is not practical [9, 10].

Cortical bone can not be penetrated with current RF delivery systems and some kind of access kit is necessary. In this study, a Jamshidi-type access system was used and through this the RF electrode was deployed. The access trochar has an insulating plastic coating. If this is damaged, RF ablation along the needle path can inadvertently occur if the non-insulated tip of the electrode comes into contact with the trochar. This is likely to be the cause for the changes along the needle track as seen in case 2 (see Fig. 2). The damage to the plastic coating was noted only after removal of the trochar. It follows that, ideally, the access track should be chosen away from a joint surface or other sensitive structure and that extra care should be taken that the electrode tip has no contact with the trochar. The electrode is ensheathed separately in an insulating cover and only direct contact between trochar and electrode tip can therefore cause problems. Some thought has to be given to the required working lengths of the various components. Technically, the use of a multi-tined expandable RF system is more demanding than using a plain electrode system. The multi-tined expandable RF system opens only as far as the single most restricted element. Therefore careful planning and some dexterity are required for probe positioning. This did not prove to be a problem.

The energy deposition with plain electrode systems (without central cooling) is in the region of a few watts, while a multi-tined expandable system can deliver power of more than 100 W. The treatment area in one application was significantly larger with multi-tined expandable systems. The system used for this study can provide a treatment area of up to 6 cm in diameter in a single application. The tissue inhomogeneities in such an area are potentially large. This manifests itself in temperature differences of up to 20% between the active elements. As long as the entire treatment volume achieves the minimum heat energy exposure necessary for cell death, this is not a problem; but it increases the risk of treatment failure. However, chondroblastomas contain relatively little vascularity and the occurrence of heat sinks, such as blood vessels, is therefore limited to the peri-tumour tissue and has here potentially a protective effect for the adjacent normal tissue. The authors assumed (though not proven in an experimental study) that the thermal conductivity and heat capacity is relatively homogenous in the lesion area.

In the use of RF probes with large treatment areas, there is increased concern of collateral damage to other structures. Several factors are to be taken into consideration. There is an inhomogenous temperature distribution in the treatment area. As the RF system used did not provide the options of individually adjusting the RF power for each electrode, and because the reaching of a certain threshold temperature in all measurement points is desired, relative over treatment of some areas occurs. This leads to an increased risk of collateral damage. This risk is increased with large treatment areas as there is a larger heat reservoir after RF power has been switched off. The shape of the RF system used was not adjustable, but the size and therefore the volume of the treatment area were, though relative over-treatment of some areas could still occur. However, in plain electrode systems, the shape of the treatment area is also not adjustable and the use of electrodes with small treatment areas is not practical for the treatment of larger areas. These are important considerations when weighing the risks and benefits of surgery or RF ablation.

Formation of gas was seen. This does not necessarily indicate surpassing of the target temperature, as gas is being formed below boiling point (temperatures significantly higher than 90°C are usually avoided as charring and cavitation can occur) [9, 10].

Intact cortical bone is a relative thermal and electrical insulator. Therefore small chondroblastomas with an intact surrounding shell of bone carry a reduced risk of collateral thermal damage. However, in large lesions, such as those treated here, with expansion and cortical thinning, these insulating properties are greatly reduced. In addition, the significant amount of thermal energy deposited over a prolonged period of time must cause a high risk of energy transfer through the cortex into adjacent soft tissue. Cartilage is particularly at risk and this has been studied in animal models [18–21]. Therefore cartilage damage must be assumed if prolonged treatment near an articular surface takes place. The risk of this must be balanced against the risk of an open surgical intervention. Standard treatment with curettage and bone grafting is invasive and can lead to premature fusion of the growth plate. Surgical access can be difficult and fairly traumatic [1–4].

It is not clear why there was development of osteochondral lesions on the surfaces of the untreated medial joint side of patient 4. It might have been due to thermal damage due to the significant energy deposition during the RF application. Interestingly though, the tibial cartilage cover on the treated side was preserved despite collapse of the underlying bone and the lateral femoral condyle did not show evidence of cartilage or chondral damage. The tibial plateau on the treatment side had collapsed before RF treatment and, despite this, the patient continued with impact sports before and after RF treatment. It is possible that sudden increase in mechanical stress significantly contributed to the development of the medial joint compartment problem. The rapid complete destruction of cartilage cover would, however, be difficult to explain as a purely mechanical problem. This requires further study.

The persistence of intrinsic bone defects after RF ablation is in keeping with the authors' experience with RF ablation of bone lesions in osteoid osteoma and metastases where also persistence of a bone defect is seen in a number of cases. This does however pose a mechanical risk for the patient. The cases of bone collapse after treatment (patients 2 and 4) illustrate the risk associated with RF treatment in weightbearing bone in a subarticular location. The alternative of standard surgical treatment for patient 2 would have resulted in significant trauma to the knee joint and would have resulted in an even bigger bone defect and likely cartilage damage.Bone graft material or bone cement was not used as these can make assessment and treatment of local recurrences difficult and it was (apparently wrongly) assumed that post-procedure bone remodelling was sufficient to protect the bone from collapse. RF ablation does not destroy bone as such and does not impair the mechanical stability in the short term. The lesional tissue is unlikely to contribute to load bearing. Medium to long-term problems can arise though from the temporarily impaired repair capability of adjacent bone which suffered necrosis during the RF ablation. Implant of bone graft material after RF ablation may be desirable in the future.

The 2 patients with a large lesion in a non-weightbearing position and a smaller lesion in a not immediately subarticular position were completely asymptomatic in clinical follow-up and no complication was encountered.

The treatment of smaller lesions is obviously desirable and RF ablation might be a valuable alternative to initial watchful waiting for lesions with difficult surgical access. Smaller lesion size results in a reduced likelihood of complications and technically easier treatment.

In conclusion, our preliminary results show that the use of multi-tined expandable electrode RF systems does allow successful treatment of large chondroblastomas in the sense that lesional tissue is destroyed; however there are potential problems and currently it has to be regarded as experimental and multi-disciplinary discussion should take place before offering this treatment to a patient. The CT-guided electrode placement requires careful planning to ensure adequate lesion treatment without over treating. Treatment near a joint surface threatens especially the integrity of cartilage and therefore long-term joint function. In weightbearing areas, the lack of bone replacement in successfully treated lesions contributes to the risk of mechanical failure. In areas where weight-bearing is not direct, successful treatment without complications was achieved and the authors think that RF ablation had a role in these cases. Each case has to be assessed individually and the potential risks and benefits of surgical and radiofrequency treatment need to be evaluated.

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