Treatment of Bone Tumours by Radiofrequency Thermal Ablation – Beyond the Osteoid Osteoma

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Abstract

Percutaneous radiofrequency thermal ablation (RFTA) is a modality of therapy suitable in treating different kind of tumours and tumour like conditions. The effects are based on converting radiofrequency into heat, leading to necrosis of the target area. Today it is considered the treatment of choice for osteoid osteomas but it has also yielded satisfactory results in other kind of neoplasms, either benign or malign. This review includes some basic technical considerations of the procedure and describes its applications in treating bone and soft tissue tumours, as adjuvant therapy or as unique technique, with curative or palliative intention. These tumours include benign conditions (chondroblastoma, enchondroma, osteoblastoma, haemangioma, eosinophilic granuloma, aneurismal bone cyst, giant cell tumour, desmoid tumour) and malign ones, mainly soft tissue and bone metastases.

Keywords

Bone neoplasms therapy, soft tissue neoplasms therapy, percutaneous radiofrequency ablation, bone tumours, intervention

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Thermal methods for tumours treatment (radiofrequency, laser, microwave, cryoablation, high intensity focused ultrasound) have become important palliative, and in some cases curative, modalities. Among these techniques, percutaneous radiofrequency thermal ablation (RFTA) has attained widespread use. RFTA bases its effect on cellular damage secondary to converting radio waves into heat in a circumscribed body area. At present, this constitutes the standard initial procedure for a definitive curative treatment of osteoid osteoma. Other benign and malign bone or soft tissue tumours and pseudotumours are also suitable for RFTA.[1] In these cases treatment is intended to be palliative or curative. Curative treatment implies that the tumour has been completely ablated. Palliative treatment aims to reduce symptoms and debulking tumour mass.[2]

This article aims to review the usefulness of radiofrequency thermal ablation in other tumour conditions different of osteoid osteoma.

Technical considerations.

The most widely used radio frequency (RF) devices for musculoskeletal applications are monopolar systems. The electric circuit is formed by using an electric generator connected to a probe or active electrode (antenna) placed inside the lesion and a large grounding pad, or dispersive electrodes placed over the skin. An alternating electric current from the RF generator flows through the electrode non insulated active tip into the patient and out through the grounding pads back to the generator. Heat is produced by resistive forces that produce ionic and molecular agitation in the tissues surrounding the electrode tip during attempts by the radio waves to return to the grounding pads[3] (see *Figure 1*).

The temperature reached in the target tissue decreases directly proportional to the distance from the electrode ($1/r^2$; r = radius of the active tip). Therefore, necrosis is focused to the volume around the electrode, making heating induced damage remote to the source of heat rather unlikely.[4] The intrinsic properties of the targeted tissue, such as heat conductivity and convection, also influence the final volume of ablation. Thermal effect can be reduced by adjacent high-flow vascular structures which act as a cooling circuitry. Heat convection to adjacent blood vessels ('heat sink' effect) can serve to protect vascular integrity from thermal damage.[5]

A rod electrode is more appropriate in bone tumour treatment because it can be inserted through a drilled hole. The distribution of heat around rod monopolar electrodes follows a cylindrical contour with rounded edges. Most heat generation is produced in tissues with lower resistance and tissue resistivity is much higher in cortical than marrow bone. Hence, cortical tissue is much more resistant to heating and has an insulating effect, when intact, protecting surrounding soft tissues and cartilage.[6]

Internal cooling of the RF electrode is a strategy to increase energy application. Internal lumina enables a perfusion of the electrode shaft with saline or water, not in direct contact with patient tissues. Internal cooling of the needle allows increase generator output, while avoiding premature carbonisation around the probe that lead to insulation and energy decay. Subsequently, internal cooling prevents or delays a deleterious increase in circuit impedance. The combination of pulsed energy application and internal cooling leads to a synergistic increase of induced coagulation. Saline infusion has been shown to be effective in enlarging the area of necrosis during radiofrequency ablation, acting as a liquid electrode with conductivity three to five times greater than that of blood and 12–15 times greater than that of soft tissue.[7] This is specially indicated in soft tissue tumour or lytic metastases constituted of soft tissue matrix. In these cases the necrosis area can also be increased using another electrode design – the cluster electrode with three straight electrodes combined in one applicator, or the umbrella multitined electrode. These increase the surface area of the RF electrode and, subsequently, increase the energy deposition within the target tissue.[8]

Close proximity to neurovascular structures may prohibit or hamper local thermal therapy. Heating at 45ºC has been shown to be neurotoxic to the spinal cord and the peripheral nerves. Interposition of bone increases the insulation but depends on the thickness of bone lamella.[9] Thermal insulation of neural structures may allow the procedure. It consists on instillation of fluid, gas or balloon interposition between adjacent non target structures and the ablation zone. In aero-dissection, CO_2 or room air can be injected with a syringe surrounding the vital structure to be protected. Saline solution is not a suitable solution due to its high electrical conductivity. Instead dextrose or glucose solution has been advocated.

Benign Osseous Tumour and Tumour-like Conditions

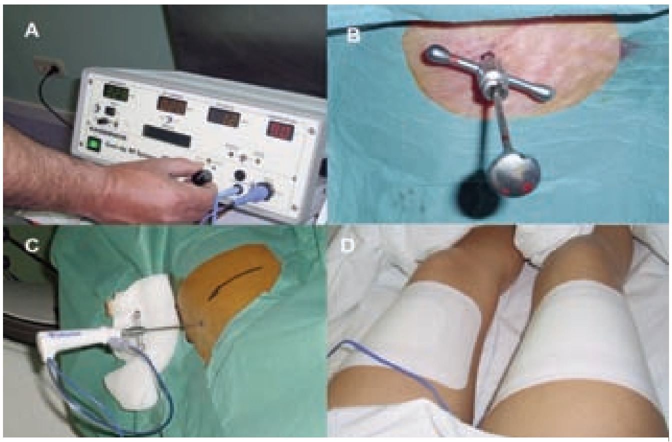
Benign bone tumours suitable for RFTA treatment include chondroid tumours, such as chondroblastoma and enchondroma, osteoblastoma, haemangioma, eosinophilic granuloma, aneurismal bone cyst and giant cell tumour. Prior histologic confirmation is necessary in these cases before planning treatment.

Chondroblastoma is a benign cartilaginous tumour that mainly arises in the epiphysis or apophysis of long bones (e.g. femur, humerus or tibia) before skeletal maturation. It accounts for approximately 1–2 % of all benign bone tumours. Surgical curettage is often difficult and RFTA has been reported as an alternative curative therapy in these cases.[10] Due to the epiphyseal location, any chosen treatment is challenging due to the risk of damaging the growth plate, resulting in growth arrest with bone shortening or deformity. Articular cartilage can also be damaged, causing premature osteoarthritis. When the growth plate is affected and years of growth still remains, we recommend partial treatment of the tumour, far of the growth plate and control until a later definitive treatment can be applied without compromising bone growth. With regard articular cartilage, it is important to depict integrity of cortical bone by computerised tomography (CT). Cortical bone has an isolating effect and, if intact, allows approaching the electrode tip closer to the cortex.[11]

Other chondral tumours, such as enchondroma, can be also suitable to be treated with RFTA, mainly when surgical treatment is a more aggressive to anatomy that a percutaneous procedure (e.g, carpal or tarsal bones).[12]

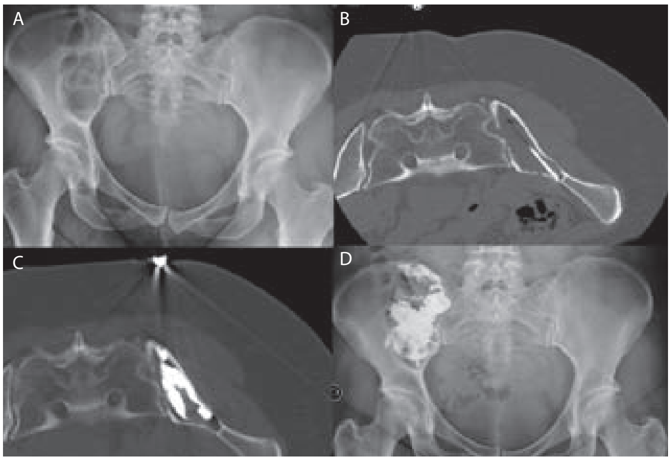
Osteoblastoma is a rare, benign, bone-forming tumour that is histologically related to the more common osteoid osteoma. Despite its benign nature, the tumour may exhibit aggressive behaviour and become larger than an osteoid osteoma (≥2 cm). Recurrences are not uncommon after classical treatment by surgical excision or curettage.[13] RFTA is a less invasive alternative. It is performed in the same way as in osteoid osteoma, using electrodes with a long active tip or a larger number of ablation sessions.[14]

Figure 1: Monopolar System



A: Monitor with two blue cables corresponding to active electrode and grounding pads. The hand is manipulating the output button; B: introductory needle; C: electrode through the introductory needle; D: grounding pads in place.

Figure 2: Giant Cell Tumour of the Right Iliac Bone



A: X-ray before procedure; B: computed tomography (CT) during ablation; C: CT during cementation; D: X-ray after procedure.

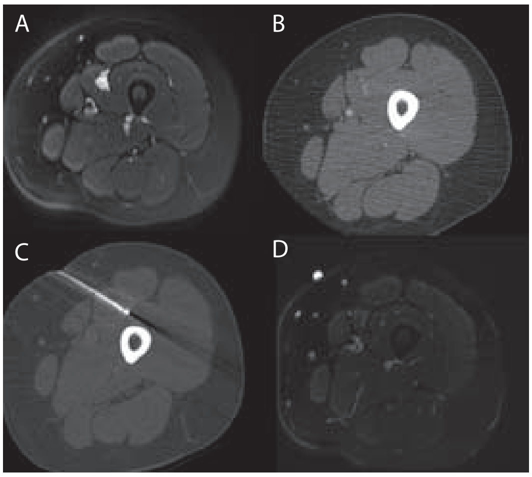
Surgery and percutaneous Ethibloc injection are traditional therapeutic options in aneurysmal bone cysts.[15] RFTA can be an alternative in some cases, as definitive treatment or adjuvant to surgery, because it achieves necrosis in a more controlled way than Ethibloc, avoiding damage of close sensitive structures, such as nerves or growth plates in children.

Surgery is the gold standard in treating giant cell tumour. Adjuvant techniques to kill residual microscopic deposits of tumour cells include the use of polymethylmethacrylate (PMMA), cryotechniques (cryosurgery) with liquid nitrogen, and, the application of chemical ablation agents such as phenol, ethanol, and H_2O_2.[16] We also consider that RFTA should be included among adjuvant therapies for giant cell tumours. In some cases, combined with cementoplasty, it can be used as curative treatment (see *Figure 2*).

Soft Tissue Tumours

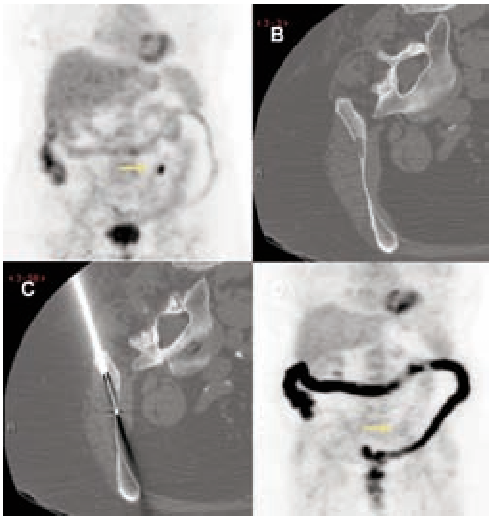
Ultrasound or CT can be used as image guidance in superficial soft tissue lesions. With ultrasound, a stable and definitive collocation of the electrode tip is mandatory because during the process of ablation the target is masked by a cloud of micro gas bubbles, avoiding

Figure 3: Impedance Control with Internally Perfused Rod Electrode



A: Axial fat saturated T2 weighted MR imaging of vastus medialis haemangioma; B: computerised tomography scan demonstrating small vessels in the nidus; C: the electrode tip inside the lesion; D: disappearance of the lesion in control magnetic resonance imaging.

Figure 4: Curative Treatment is Reserved for Slow-growing Metastases when Less than Three Proven Locations and Less than 3 cm in Diameter



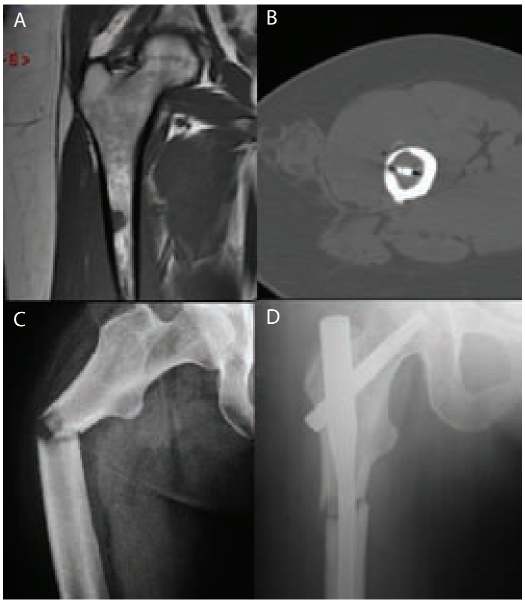
A: Metastasis of breast carcinoma depicted as an area of increased uptake on positron emission tomography (PET) scan (arrow); B; lytic lesion on computerised tomography (CT); C: CT during ablation; D: PET after ablation with disappearance of the iliac uptake (arrow).

appropriate visualisation after the beginning of the procedure. With computed tomography, contrast agent is necessary for an improved visualisation of the soft tissue tumour. A quick planning of the electrode positioning is mandatory because contrast of the lesion decrease with iodine contrast clearance.

Our experience in treating soft tissue tumours is limited to benign hemangioma, with three successfully treated cases. We used impedance control with internally perfused rod electrode in order to increase the diffusion of heat (see *Figure 3*). Isolated reports of usefulness of the technique in either vascular or lymphatic malformation have been published.[17]

RFTA is also being used as an alternative to conventional treatment (i.e., surgery, radiation, and chemotherapy) in selected cases of malignant or aggressive tumours in musculoskeletal soft tissues. Most of the times, treatment is intended to be palliative.

Figure 5: Prior Ablation Helps Avoiding Tumour Dissemination and Reducing the Amount of Intratumoral Bleeding



A: Metastasis of lung cancer in femoral shaft depicted as a small round lesion on coronal T1 weighted MR imaging; B: computerised tomography during ablation; C: a pathological fracture developed two months after procedure; D: it was treated with percutaneous femoral nailing.

In desmoid tumours (aggressive fibromatosis), when surgery is considered unsuitable, RFTA can be considered an alternative to radiotherapy or pharmacotherapy for local control of the disease.[18] Cases in which RFTA has been used to reach a more definitive treatment of primary malignant soft tissue tumours and its metastases have been reported, such as rabdomysarcoma[19] and leiomyosarcoma.[20] Soft tissue metastates from primary tumours such as lung and breast cancer can be painful; RFTA of these lesions can also be a worthwhile palliative treatment for these patients.[21]

Treatment of Malignant and Metastatic Bone Tumours

Nowadays, treatment of most malignant bone tumours consists of surgical resection with clear margins followed by adjuvant therapy if indicated. RFTA has not a definitive role in these conditions. There is a report about treatment of a low grade chondrosarcoma of the femoral head-neck junction by RFTA because it was suspected to be a benign tumour. It developed a pathologic fracture and the patient underwent surgery with total hip arthroplasty. In the specimen, necrosis covered all tumour and three years of follow-up has shown neither local tumour recurrence nor distant metastases.[22] Therefore, as in benign chondral tumour, RFTA might be an alternative in malignant chondral tumours in challenging localisations to surgical removal. It could even be speculated if in the future RFTA may be suitable in palliating pain in selected cases of incurable primary bone tumours and its metastases. Bone tumour ablation has two specific advantages over radiotherapy. Pain relief from RFTA is immediate and can target lesions in a more localised fashion than standard radiotherapy.[23] Combined use of both treatments can also be considered.

Palliative use of RFTA for pain from bone metastases is a more widespread practice, mainly in patients refractory to medical treatment or radiotherapy. This unresponsive group is estimated to be about 30 %.[24] Owing to the distribution of the red bone marrow, the most common localisation of bone metastases is the spine, followed by pelvis, femur, skull and other long bones. Bone pain is present at the diagnosis of neoplastic bone disease in 58–73 % of patients when bone lesions are lytic or mixed, but in only 42 % of patients with osteoblastic metastases.[25] The cause of pain can be multifactorial: microfractures, injury of nerve endings in the periosteum or endosteum, indirect cytokine or interleukin mediated stimulation of pain, or extension to sensitive nerves of the soft tissues.[26] The involved mechanism in pain relief with RFTA may be a decrease in intratumoural pressure, a decrease in cytotoxin release, decreased pressure on adjacent anatomy, or destructive ablation of sensitive nerve fibres.[27]

Previous studies have shown the usefulness of using radiofrequency ablation for pain relief in patients with painful bone metastases. In metastatic bone lesions of known primary tumours, biopsy can be performed in the same session as RFTA, before introducing the electrode. Most of the treatments are intended to be palliative. Reduction of pain can lessen the use of narcotics and provide another non-sedating treatment options for cancer patients. It is mainly indicated for patients with osteolytic or mixed-type painful bone metastases who have not responded to other standard forms of therapy. In palliative ablation of painful sclerotic bone metastases is quite often necessary to reduce power in order to avoid impedance increase that may stop the generator output.[28] A tumour-free treatment margin is not a requisite to palliation.

Curative treatment is reserved for slow-growing metastases when less than three proven locations and less than 3 cm in diameter[29] (see *Figure 4*). As in surgical resection, margin has to be considered. A curative tumour ablation treatment must include at least 0.5–1 cm margin of healthy tissue around the target lesion to avoid local recurrence.[30]

The combined use of RF ablation and cementoplasty appears to be useful in achieving tumour necrosis and stabilising the ablated lesions. The coagulation necrosis produced by RF ablation may promote a homogenous distribution of the bone cement within the ablated lesion.[31] Indications of combined procedures are mainly osteolytic tumours (e.g., metastasis, multiple myeloma, lymphoma) that are located in weight-bearing bones, in order to prevent the risk of secondary fracture, such as in the vertebral body, acetabulum, and condyles. In these cases association of CT and fluoroscopy is advised. When multislice fluoro-CT is not available, CT is used first for the ablation procedure, and fluoroscopy second, with a C-arm introduced into the CT room, for real-time imaging of cement injection. The injection should be delayed until the tumour temperature has decreased to normal levels to avoid quickly hardening of the cement. When we perform the combined procedure we treat preferentially sites close to interfaces with normal bone and tumour in order to avoid progression toward healthy bone structures. The interface between tumour and periosteum is also a main source of pain.[32]

In weight bearing long bones the debilitating effect of RFTA might increase the risk of developing a pathological fracture. In these cases prophylactic bone nailing is indicated.[33] Prior ablation helps avoiding tumour dissemination and reducing the amount of intratumoural bleeding (see *Figure 5*).

Although most of the burn secondary to RFTA have been described at points of contact of the grounding pads, it can also happens at the entrance point of the electrode due to tears of the insulation, mainly in large tumour, when the electrode has to be repositioned in repeated session. In these cases we recommend careful visual check of the electrode in each step because small flap of the insulation cover can be detected. Repetitive touching of the skin during the procedure may also detect increase temperature of the skin that may reveal undetected failure of the insulation of the electrode.

In summary, we review the usefulness of RFTA in treating musculoskeletal neoplasm different of osteoid osteoma. With increase experience in using thermal ablation, more challenging localisations and tumour types are considered suitable to be treated with RFTA as the only treatment or adjuvant to traditional techniques. ■

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