Radiofrequency Ablation of Bone with Cooled Probes and Impedance Control Energy Delivery in a Pig Model: MR Imaging Features

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PURPOSE: To determine the coronal marrow ablation length and detect cortical thinning after radiofrequency ablation (RFA) of bone in a pig model.

MATERIALS AND METHODS: Twelve pigs underwent RFA with a 1- or 2-cm single internally cooled electrode placed at the mid-diaphyseal point of their long bones at 1, 7, or 28 days before euthanasia. Twelve minutes of impedance control radiofrequency energy was delivered at maximum output from a 200-W generator. Pigs were imaged with axial and coronal turbo spin-echo (SE) T1- and T2-weighted frequency-selective fat suppression sequences by using spectral presaturation with inversion recovery (SPIR). A radiologist blinded to the timing of the treatment and the results of other imaging sequences measured the coronal ablation zone length and cortical thickness. The pigs were euthanized, and the ablated bone underwent histologic examination.

RESULTS: At SPIR imaging, the zone of marrow ablation was defined as an area of low signal intensity surrounded by a high-signal-intensity band. At T1-weighted imaging, the zone of marrow ablation was defined as a heterogeneously isointense area surrounded by a low-signal-intensity band. The mean (±standard deviation) coronal marrow ablation zone measurement with SPIR imaging at 28 days was 47 mm ± 9 (range, 34–73 mm) for the 1-cm electrode and 51 mm ± 7 (range, 33–67 mm) for the 2-cm electrode. Two humeral fractures occurred at 21 and 28 days after therapy. Thinning of the cortex adjacent to the electrode insertion site was identified in the humeral group only.

CONCLUSION: The change in the marrow signal intensity with impedance-controlled RFA is larger than that reported for temperature-controlled protocols. RFA leads to bone weakening.

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Abbreviations: RFA = radiofrequency ablation, SE = spin echo, SPIR = spectral presaturation with inversion recovery

RADIOFREQUENCY ablation (RFA) has been applied successfully in bone for benign and malignant disease. Non-cooled 5-mm exposed tip electrodes with low output radiofrequency generators and 4- or 6-minute treatment times have been used successfully for the therapy of osteoid osteoma since the early 1990s (1). In the short-to-medium term, RFA can substantially reduce pain when applied for symptomatic bone metastases (2).

Generators now have higher outputs and can use specialized internal software to control energy delivery to the lesions by monitoring electrical resistance (3). Such modifications enable larger energy delivery and tissue necrosis, facilitating the treatment of larger solid lesions (3). Modern radiofrequency equipment enables the ablation of a sphere of soft tissue measuring up to 5 cm with a single electrode placement (4). The extension of the ablation zone can lead to non-target therapy to adjacent tissues such as the skin and nervous tissue (5,6).

In the largest series of 126 patients with osteoid osteoma treated with a 0.5-cm electrode and a low-output generator under manual control for 6 minutes with at least 2-year follow-up, treatment was successful in 89% of patients; this series is limited, however, because 28% of the treatment population was lost to follow-up (7). In the second largest published series by Vanderschueren et al (8), 76% of 97 patients had success after one treatment.

High-energy protocols have the po-

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tential to deliver larger zones of thermal ablation in bone and improve the success of therapy for osteoid osteoma and reduce the number of electrode placements in the therapy of malignant osseous lesions (8).

In this study we applied an energy protocol in pig bone, believing that a larger ablation zone would be produced than that reported with different energy delivery techniques. The purpose of this study was to determine the coronal marrow ablation length and detect cortical thinning after RFA of bone in a pig model.

MATERIALS AND METHODS

This study received ethical approval from the institutional review board to perform RFA in 12 pigs. Three- to 6-month-old white male farm-bred pigs underwent RFA. The mean weight of each pig at treatment was 62 kg (range, 35–73 kg). The treatment weight was selected so that the animal would weigh 70–75 kg at euthanasia. Ablation or control lesions were created on all the long bones except the fibula. Control lesions were created by using the same coaxial technique and electrode placement; however, the electrode was not activated. With the pigs under general anesthesia, the long bones were treated at a time period before euthanasia. Control lesions were created at the same time or a second general anesthesia procedure was performed for creation of further ablation lesions on the contralateral side (**Table 1**). The 1-day treatment group was halted after three pigs because a demarcated therapeutic zone was not seen at magnetic resonance (MR) imaging.

Table 1
Summary of Treatment Groups

Pig No.	Right Side	Left Side
1	Control	1 d
2	Control	7 d
3*	Control	28 d
4†	1 d	28 d
5	1 d	7 d
6	28 d	Control
7‡	28 d	Control
8	28 d	Control
9	28 d	Control
10	7 d	Control
11	7 d	Control
12	7 d	Control

* Left humeral fracture 21 days after RFA mandated euthanasia before planned 28 days.
† Skin burn at electrode placement site at the treatment of the right tibia mandated euthanasia 2 hours after therapy rather than at 1 day.
‡ Right humeral fracture occurred 28 days after RFA.

Anesthesia Protocol

Premedication.—For a 50-kg pig, premedication was performed with 2.5 mL of ketamine hydrocloride solution (Ketamine; Vetoquinol, Bicester, England, 5 mg/kg, 100 mg/mL) followed by 2.5 mL of azaperone (Stresnil; Janssen Pharmaceutica, Beerse, Belgium, 2 mg/kg, 40 mg/mL). Then, 1 mL of butorphanol (Torbugesic; Fort Dodge Animal Health, Southampton, England, 0.2 mg/kg, 10 mg/mL) was administered by deep intramuscular injection in the neck muscle. Loss of righting reflex occurred 10 minutes later. A 21-gauge intravenous cannula was inserted into the marginal ear vein and secured.

Anesthesia.—Anesthesia was administered by a qualified veterinarian anesthetist. Endotracheal intubation was performed with a cuffed endotracheal tube. Antibiotic prophylaxis with a second-generation cephalosporin, 750 mg of cefuroxime sodium (Zinacef, Britannia Pharmaceuticals, Redhill, England), was intravenously administered at induction of anesthesia.

Radiofrequency Technique

All RFA procedures were performed by the authors. The pig was placed in a lateral position on an analog fluoroscopy table (Siemens, Erlangen, Germany) with the side for therapy up. Foam pads were placed under both legs to keep them perpendicular to the incident x-ray beam, and the limbs were secured. Fluoroscopy was performed, and the midpoint of the diaphysis was marked with a radiopaque ruler.

The back of each pig was shaved. Two 10.5 × 18-cm self-adhesive wire mesh grounding pads (Valleylab, Boulder, Colo) with coupling gel were placed on the pigs' backs. The pigs' limbs were prepared and draped. An 11-gauge Jamshidi needle (Allegiance Healthcare, McGaw Park, Ill) was inserted through a 3-mm incision and used to reach the lateral cortex at the mid-diaphyseal point. When the trocar was removed, it provided a protected tract for the near cortex to be drilled with a 1.6-mm nonthreaded K-wire (MicroAire, Charlottesville, Va), which was modified by marking the shaft in 1-cm increments. Drilling was stopped when the K-wire projected into the medulla of the bone. The K-wire was then removed and the 17-gauge (1.5-mm) single internally cooled radiofrequency electrode (Cool Tip; Valleylab) inserted through the outer cannula of the Jamshidi needle into the defect created by the K-wire.

A 2-cm exposed tip electrode was used in the femur, tibia, and humerus. A 1-cm exposed tip electrode was used in the radius and ulna. The pig limb was rotated under fluoroscopic screening guidance to ensure that the electrode tip was in the marrow cavity with the near extent of the exposed electrode at the periosteum. The Jamshidi needle cannula was withdrawn and secured with adhesive tape.

A 200-W radiofrequency generator (RFG-3C; Radionics, Burlington, Mass) was used. The RF power was manually increased over the first 5 seconds of the treatment to maximum output, and then impedance regulated delivery was performed for 12 minutes.

A peristaltic pump (Watson-Marlow, Medford, Mass) was used to infuse a water solution at near 0°C into the lumen of the electrodes at a rate of 70–80 mL/min to maintain a tip temperature of less than 10°C.

The procedure was considered to be technically successful if the electrode was placed in the cortex and 12 minutes of radiofrequency therapy was delivered.

Non-steroidal anti-inflammatory medication was administered. The pig was recovered, mobilized, and placed in a pen. A veterinarian determined if the pig required further analgesia. None of the pigs required further analgesia.

MR Imaging Protocol

Euthanasia was performed with an overdose of pentobarbitone sodium (200 mg in 1 mL) (Euthatal; Vericore, Dundee, Scotland) 1 day, 7 days, or 28 days after therapy. Imaging was per-