Comparison of Acute Histologic and Biomechanical Effects of Radiofrequency Ablation and Cryoablation on Periarticular Structures in a Swine Model

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ABSTRACT

Purpose: To compare the acute effects of radiofrequency (RF) ablation and cryoablation on the structural integrity of nontarget periarticular tissues that may be placed at risk during percutaneous bone ablation.

Materials and Methods: RF ablation and cryoablation were separately performed on tendon, articular cartilage, and ligament in an ex vivo porcine model by using standard bone ablation protocols. Gross and histopathologic analysis was performed on cartilage and tendon (n = 6 for each treatment group, n = 5 controls). Tendon lengths were measured before and after ablation. Biomechanical tensile testing was performed on each ligament sample after ablation, with quantification of ultimate load at failure and linear stiffness (n = 7 ligaments in treatment and control groups).

Results: RF ablation and cryoablation injured chondrocytes within the ablation zones but caused minimal effects on gross and histologic cartilage architecture. Cryoablation resulted in minimal gross and histologic effects on tendon whereas RF ablation resulted in marked disruption of collagen fibers and significant longitudinal shortening ($P = .002$). Similarly, cryoablation did not alter ligament strength or stiffness compared with control, whereas RF ablation resulted in a significant decrease in tensile strength and stiffness compared with control and cryoablation samples ($P < .001$).

Conclusions: Neither RF ablation nor cryoablation resulted in significant acute changes in cartilage architecture. However, RF ablation resulted in marked disruption of tendon architecture, tendon shortening, ligament weakening, and loss of ligament stiffness, whereas cryoablation had no significant effect on any of these parameters. These findings suggest that cryoablation may have fewer negative acute effects than RF ablation, although long-term outcomes are currently unknown.

ABBREVIATIONS

ACL = anterior cruciate ligament, H&E = hematoxylin and eosin, RF = radiofrequency

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Radiofrequency (RF) ablation and cryoablation induce cellular injury and death through different mechanisms. At temperatures greater than 46°C, RF ablation heats the targeted tissue by the frictional agitation of ions, resulting in irreversible cellular injury from coagulation of cytosolic and mitochondrial proteins (1,2). In contrast, at temperatures of approximately −20°C to −40°C, cryoablation induces extreme hypothermia in the tissues surrounding the cryoablation needle by the endothermic expansion of argon gas within the needle. This results in cellular injury and death via a variety of proposed mechanisms, such as

cell membrane disruption, cell dehydration, protein denaturation, and ischemia (3,4).

RF ablation and cryoablation have been reported as effective modalities for the treatment and palliation of painful osseous metastases, soft-tissue metastases, and osteoid osteomas (5–10). Although the palliative effect on painful bone metastases is similar for RF ablation and cryoablation, a lower amount of postprocedural pain and shorter recovery time has been reported after treatment with cryoablation (10). In addition, although RF ablation and cryoablation have demonstrated efficacy in the treatment of benign and malignant osseous lesions, the tolerances of periarticular structures to nontarget ablation from these two modalities are not well established. Therefore, the present study was conducted in an ex vivo porcine model to compare the acute ablative effects of RF ablation and cryoablation on the structural integrity of nontarget periarticular tissues that may be placed at risk during percutaneous bone ablation.

MATERIALS AND METHODS

Tissue Sample Acquisition and Preparation

The present study on postmortem tissue samples was exempted from formal institutional animal care and use committee review. The hind limbs were harvested from freshly slaughtered adult farm pigs (204–272 kg) within 2 hours of death and immediately stored on ice for a maximum of 48 hours before testing. Articular cartilage, tendon, and ligament were represented by the patellar articular cartilage, Achilles tendon, and anterior cruciate ligament (ACL), respectively. From each hind limb, the entire bony patella was dissected free from its tissue attachments, leaving an intact articular cartilage surface. The body of the Achilles tendon was harvested from the distal calcaneal attachment to the musculotendinous junction, comprising a 7–10-cm length of tendon. ACL samples consisted of the entire dissected porcine knee complex (without the patella), including approximately 25–30 cm of intact femur and tibia, with all muscle, ligaments, tendon, and soft tissues removed except the ACL. All tissues were stored on ice and wrapped with gauze soaked in normal saline solution to prevent desiccation between tissue preparation and ablation.

For gross and histopathologic assessment of cryoablation and RF ablation relative to control samples, the patella and Achilles tendon were harvested from 17 hind limbs from nine swine and randomly divided into the following groups: cryoablation ($n = 6$), RF ablation ($n = 6$), and control ($n = 5$). To test the effects of cryoablation and RF ablation on ACL tensile properties, seven matched pairs of hind limbs from seven swine were randomized so that one knee in the pair underwent cryoablation and the other underwent RF ablation to optimize direct comparison of RF ablation versus cryoablation. Seven additional unpaired knees from four animals served as controls.

Thermal Ablation Technique

Cryoablation was performed by using a single 17-gauge (1.5-mm) cryoablation needle (IceRod; Galil Medical, Arden Hills, Minnesota). RF ablation was performed with a single 17-gauge, 7-mm active-tip electrode (Cool-tip; Coviden, Boulder, Colorado). Procedures were performed by an attending interventional radiologist (C.Y.K.) with 5 years of experience with thermal ablation procedures. For cartilage experiments, the ablation probe was inserted perpendicular to the articular surface with the tip slightly embedded in the subchondral bone. For tendon and ACL experiments, the ablation probe was inserted perpendicular to the midportion of the tendon or ACL until the tip was a few millimeters beyond the exit surface. To control for the actual probe puncture, all control tissues were punctured with a 17-gauge probe without performance of thermal ablation.

All thermal ablation procedures were performed at room temperature. Cryoablation was performed by using standard 10-minute freeze/8-minute active thaw/10-minute freeze cycle, with a temperature nadir of $-40^{\circ}C$ (8). Samples were allowed to return to room temperature before any manipulation. RF ablation was performed by using a standard 10-minute heating cycle, with temperature maintained between $90^{\circ}C$ and $100^{\circ}C$ (6). Control samples underwent only puncture with a 17-gauge RF ablation electrode without heating the tissue.

Gross Pathologic Analysis of Cartilage and Tendon

Gross observations were made on the appearance of the cartilage and tendon after ablation in comparison with controls. The length, width, and thickness of the tendons treated with RF ablation, cryoablation, and sham ablation were measured with calipers before and after ablation.

Histopathologic Analysis of Cartilage and Tendon

Histopathologic analysis was performed by an attending pathologist (D.M.C.) with 5 years of experience. Previously described methods for histopathologic analysis of joint tissues were used (11). After overnight decalcification, patellar cartilage samples were sectioned through the center of the probe insertion site, parallel to the direction of the probe. Tendon samples were sectioned through the center of the ablation zone or needle puncture site, parallel to the direction of the needle and the tissue fibers. All sections were stained with hematoxylin and eosin (H&E) in standard manner, as well as with picrosirius red to improve visualization of the collagen structure (12). All H&E-stained samples