MR Imaging-guided Percutaneous Cryoablation of the Prostate in an Animal Model: In Vivo Imaging of Cryoablation-induced Tissue Necrosis with Immediate Histopathologic Correlation

Maurice A.A.J. van den Bosch, MD, PhD, Sonal Josan, PhD, Donna M. Bouley, VMD, PhD, Jin Chen, PhD, Harcharan Gill, MD, Viola Rieke, PhD, Kim Butts-Pauly, PhD, and Bruce L. Daniel, MD

PURPOSE: To evaluate the feasibility of magnetic resonance (MR) imaging–guided percutaneous cryoablation of normal canine prostates and to identify MR imaging features that accurately predict the area of tissue damage at a microscopic level.

MATERIALS AND METHODS: Six adult male mixed-breed dogs were anesthetized, intubated, and placed in a 0.5-T open MR imaging system. A receive-only endorectal coil was placed, and prostate location and depth were determined on T1-weighted fast spin-echo (FSE) MR imaging. After placement of cryoprobes and temperature sensors, three freezing protocols were used to ablate prostate tissue. Ice ball formation was monitored with T1-weighted FSE imaging. Tissue necrosis area was assessed with contrast-enhanced weighted MR imaging and compared with histopathologic findings.

RESULTS: A total of 12 cryolesions (mean size, 1.2 cm) were bilaterally created in six prostates. Ice ball formation was oval and signal-free on T1-weighted FSE sequences in all cases. Postprocedural contrast-enhanced MR imaging typically showed a nonenhancing area of low signal intensity centrally located within the frozen area, surrounded by a bright enhancing rim in all cases. On histopathologic examination, two distinct zones were identified within cryolesions. Centrally, a necrotic zone with complete cellular destruction and hemorrhage was found. Between this necrotic zone and normal glandular tissue, a zone of fragmented and intact glands, interstitial edema, and rare acute inflammatory cells was seen. Correlation between nonenhancement on contrast-enhanced weighted MR images and tissue necrosis on pathologic examination was consistent within all six dogs.

CONCLUSIONS: MR imaging–guided cryoablation of the prostate is technically feasible. The nonenhancing area on postablation contrast-enhanced weighted MR imaging accurately predicts the area of cryoablation-induced tissue necrosis on pathologic analysis.

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Abbreviations: FSE = fast spin-echo, SPGR = spoiled gradient-recalled [imaging]

CRYOABLATION, ie, tissue necrosis caused by freezing, is increasingly used for minimally invasive tumor cell destruction (1). Recent advances in noninvasive imaging techniques, including ultrasound (US) and magnetic resonance (MR) imaging, have fueled the interest in image-guided cryoablation for local control of prostate cancer (2–4). The main goal of imaging during the cryoablation procedure is to accurately monitor and control of the extent of the frozen region, ie, the ice ball (5).

Cryoablation for treatment of localized prostate cancer is currently carried out under transrectal US guidance (4). However, US has some limitations with regard to monitoring the freezing procedure. The critical angle-shadow-

From the Departments of Radiology (M.A.A.J.v.d.B., B.L.D.), Pathology (D.M.B.), and Urology (H.G.), and Lucas MRS Imaging Center (S.J., J.C., V.R., K.B.P.), Stanford University, 1201 Welch Road, Stanford, CA 94305-5488. Received January 15, 2008; final revision received and accepted October 23, 2008. **Address correspondence to** M.A.A.J.v.d.B.; E-mail: maaj.vandenbosch@gmail.com

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a. b.

Figure 1. **(a)** The open 0.5-T MR imager. **(b)** MR imaging–compatible cryoablation probes (17 gauge) were percutaneously inserted thorough the anterior abdominal wall. (Available in color online at *www.jvir.org*.)

ing effect causes the ice ball to cast a shadow that is larger than the ice ball itself. As a consequence, the majority of the frozen tissue remains invisible and cell destruction at the rim of the shadow may not be uniformly complete.

MR imaging is a more promising cryoablation guidance modality than US for several reasons. First, experimental studies have proven the capability of MR imaging to image the extent of frozen tissue with high accuracy and excellent contrast between normal and frozen tissue as a result of the signal void of frozen water on all conventional MR imaging sequences (6,7). Second, MR imaging depicts the ice ball boundaries well in three dimensions. Third, MR imaging potentially allows noninvasive quantitative temperature mapping within the ice ball and its surrounding tissue with the use of ultrashort–echo time MR imaging and proton resonance frequency shift thermometry, respectively (8). Fourth, contrast-enhanced MR imaging potentially has the ability to visualize the acute necrotic zone because of the lack of perfusion (9).

It has been demonstrated that cell damage is related to the particular thermal parameters experienced during freezing, with cellular death ranging from 0% at the ice ball boundary to 100% at the center of the ice ball (10,11). Accurate imaging of the ice ball with contrast-enhanced MR imaging is of value clinically because it could be used to evaluate if repeated or extended treatment is necessary. This experimental study was designed to evaluate the feasibility of MR imaging-guided percutaneous cryoablation of normal canine prostates and to identify MR imaging features that accurately predict the area of cryoablation-induced tissue necrosis at a histopathologic level.

MATERIALS AND METHODS

All animal experiments were approved by the institutional animal care and use committee of Stanford University. Six adult male mixed-breed dogs were anesthetized, intubated, and placed supine in a 0.5-T Signa open MR imaging system (GE Medical Systems, Milwaukee, Wisconsin). A receive-only endorectal coil was placed in the rectum. MR imaging–compatible cryoablation probes (17-gauge; Galil Medical, Plymouth Meeting, Pennsylvania) and Luxtron (Luxtron, Santa Clara, California) and 22-gauge fiberoptic temperature sensors were inserted through the anterior abdominal wall into the normal canine prostate (**Fig 1**).

The prostate's exact location and depth in relation to skin were determined on T1-weighted fast spin-echo (FSE) imaging (echo train length of four; repetition/echo time, 300/8–14 msec [minimum effective]; ±16 kHz receiver bandwidth; 256 × 128 matrix; 5-mm section thickness; 100cm field of view) (12). Cryoprobes and Luxtron fiberoptic temperature sensors were inserted percutaneously into the prostate in a stepwise fashion. Each step was controlled with use of the T1-weighted FSE images as described earlier. After correct placement of the cryoprobes and temperature sensors was confirmed, three different freezing protocols were used to ablate prostate tissue: (i) single-probe ablation, final temperature between −10°C and −40°C, one freeze/thaw cycle (indicating one ablation with a single probe; protocol A); (ii) single-probe ablation, final temperature below −40°C, two freeze/thaw cycles (indicating two ablations per probe; protocol B); and (iii) multiple four-probe ablation with probes 5 mm apart, final temperature between 0°C and −10°C, one freeze/thaw cycle (indicating one ablation per probe; protocol C).