

MR Guided High Intensity Focused Ultrasound Bone Ablation Assessed with MR, PET, and MDCT imaging

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Purpose: MR-guided high intensity focused ultrasound (MRgHIFU) is a powerful technique for thermally ablating focal lesions. The most frequent current bone application is pain palliation of bone metastases refractory to radiation therapy.¹ Treatment begins with acquisition of high quality MR images of the targeted tissue. MR thermometry sequences can be used to carefully monitor the degree of energy deposition. Post-contrast imaging following treatment documents the efficacy of the therapy. While the number of potential MRgHIFU applications is rapidly expanding across all organ systems, few studies have demonstrated the fundamental effects of HIFU on normal bone using modern imaging modalities.² The purpose of this study was to clearly delineate post-treatment changes in bone following HIFU on MR, PET and MDCT imaging in a swine model.

Methods: All experimental procedures were done in accordance with National Institutes of Health guidelines for humane handling of animals and received prior approval from the local Institutional Animal Care and Use Committee. We performed MRgHIFU using an ExAblate® 2000 system (InSightec, Haifa, Israel) integrated with a 3.0 Tesla MR scanner (GE Healthcare, Waukesha, WI, USA) in a swine model. Multiplanar T2-weighted fast spine echo (FSE) and LAVA 3D spoiled gradient echo images were acquired for treatment planning. Two discrete ovoid treatment targets were prescribed at each proximal diaphysis and distal metadiaphysis of the right femur. Four sonications were used to create each lesion at 1.05 MHz with a phased array transducer of 208 elements embedded within the scanner table. During the course of the treatment, the power level, focus size, and beam angle were varied in order to produce consistent thermal heating. Each sonication pulse was 20 seconds in duration with an average acoustic power of 31 W and average increased temperature at the bone-soft tissue interface to 79 °C. Follow-up MR imaging was performed five days after intervention using multiplanar T2-weighted FSE (TR/TE/flip angle=2s/100ms/90) and delayed contrast enhanced segmented inversion recovery fast gradient echo (TR/TE/flip angle=1.5ms/15.2ms/15), LAVA 3D spoiled gradient echo sequences. A dose of 0.1mmol/kg Gd-DTPA was delivered 10min before imaging to assess the effect of ablation. Dynamic ¹⁸NaF-PET images were also obtained five days post-HIFU concordantly with contrast-enhanced MDCT images. The K1 uptake rate constant (one tissue compartment) was calculated at the ablation sites and compared to the contralateral untreated limb. Additionally, high-resolution peripheral quantitative computed tomography (HR-pQCT) images were obtained of specimen samples from the treated and contralateral limbs. Histopathology was performed to characterize cellular changes at the targets.

Results: Using MRgHIFU we created two focal ablation lesions within each right femur. Follow-up T2-weighted imaging demonstrated interstitial edema layering focally along the targeted bone margins (Figure 1A). Delayed contrast enhanced MR images demonstrated discrete ovoid regions of hypoenhancement, which correlated specifically with the bone targets (Figure 1B). Dynamic ¹⁸NaF-PET imaging demonstrated focal regions of photopenia at the treatment sites (Figure 1C) with K1 equal to approximately zero at the treated foci within the femur compared to an average of 0.17 and 0.24 mL-gm⁻¹-min⁻¹ at the corresponding sites on the contralateral side. Contrast enhanced MDCT failed to demonstrate the lesions. There was no significant difference between the treated and untreated limbs on HR-pQCT at five days.

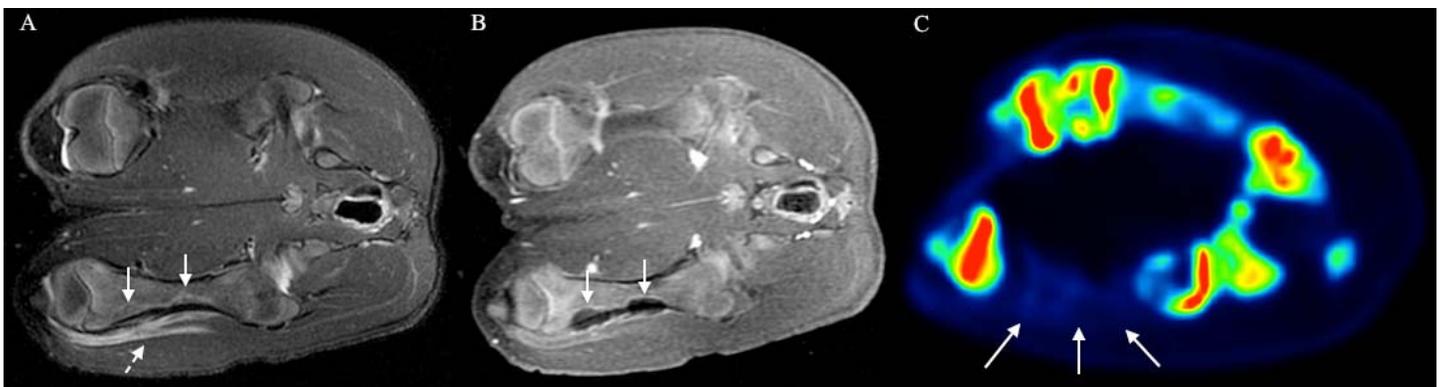


Figure 1. Axial MR and PET post-treatment images showing the ablation sites. A. T2-FSE shows subtle ovoid hypointensities with hyperintense rims corresponding to the two foci of treated bone (solid arrows). Adjacent edema layers along the lateral femur margin (dashed arrow). B. Delayed contrast enhanced MR image demonstrates two ovoid foci of hypoenhancement correlating with the ablated target sites (solid arrows). C. Summation image from dynamic ¹⁸NaF-PET shows markedly decreased radiotracer uptake in the treated femur (solid arrows) compared with untreated femur.

Conclusion: This swine model demonstrated the structural and functional changes following MRgHIFU ablation of the bone. MRI and ¹⁸NaF-PET imaging showed focal hypoenhancement of ablated bone and impaired radiotracer uptake (perfusion), respectively. Contrast enhanced MDCT and HR-pQCT failed to demonstrate the lesions. The study supports the usage of MRgHIFU in treating focal pathologic lesions in bone.

References: 1. Gianfelice D, Gupta C, Kucharczyk W, et al. Palliative treatment of painful bone metastases with MR imaging—guided focused ultrasound. *Radiology*. 2008; 249(1):355-363. 2. Kopelman D, Inbar Y, Hanannel A, et al. Magnetic resonance guided focused ultrasound surgery. Ablation of soft tissue at bone-muscle interface in a porcine model. *Eur J Clin Invest*. 2008; 38(4):268-275.