MRI-Guided Radiofrequency Ablation: Three-dimensional Correlation of Hyperacute and Subacute MR Lesion Images with Tissue Response

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Introduction

Solid tumors and other pathologies are treated using radio-frequency (RF) ablation under interventional MRI (iMRI) guidance [1,2]. There are many advantages of iMRI including excellent soft tissue contrast, no ionizing radiation, and the ability to image at any angle. To monitor ablation with iMRI, one can measure temperature during the procedure and/or MR signal amplitudes following treatment. We are investigating this unique ability to monitor treatment by comparing MR images of the thermal lesion to cellular damage as seen histologically using three-dimensional (3D) registration techniques. If MR measurements can accurately predict regions of cell death and damage, iMRI will be quite advantageous for optimally treating tumor while sparing nearby normal tissues of critical importance.

Methods

A low-field, open MRI system was used to guide an ablation probe into in vivo rabbit thigh muscle and acquire MR volumes post-ablation. Ablation occurred by heating the probe tip to 90°C for 2 minutes with an RF energy source. To examine latent tissue changes in response to the interventional procedure, the rabbits were sacrificed either 45 minutes or 4 days post-ablation. After fixation, we sliced and photographed the tissue at 3 mm intervals, using a specially designed apparatus, to obtain a volume of tissue images. Digital histological images were obtained, and regions of tissue damage were labeled using a video microscopy system with a motorized stage. We aligned the histological and MR image data using a 3D registration method with an accuracy estimated to be 1.32 mm ± 0.39 mm (mean ± SD).

Results

To compare MR and tissue response 45 minutes post-ablation, we copied the boundary of tissue necrosis marked in the histological samples to the registered MR images as shown in Figure 1. In this necrotic region, the cells were characterized by contraction band necrosis and a loss of muscle's birefringence which has been previously shown to correspond to a region of eventual necrosis [3]. This tissue damage boundary matched closely to the outer boundary of the hyperintense region in MR images. To further investigate the correlation of MR and histology images, we compared the necrotic boundary with the outer boundary of the hyperintense region marked by an observer in the T2-weighted MR images. For five rabbit experiments, the boundaries were well aligned in 14 registered histology slices with an absolute distance of 0.96 ± 0.34 mm. The signed distances were not significantly different from zero, which is good evidence of insignificant bias between boundaries.

A comparison of MR and tissue response 45 minutes post-ablation showed that outer boundary of hyperintense region in MR images closely corresponds to the region of dead or irreversibly damaged cells in histology. These results are consistent with our findings from experiments with rabbits sacrificed 4 days post-ablation, which show the complete extent of the cell death in a well demarcated region of necrosis in histology (Figure 2). A correlation of histology and MR images 4 days post-ablation showed the boundary of cell death closely corresponds to the outer boundary of the hyperintense region with a mean absolute distance for 20 tissue slices of 0.95 ± 0.34 mm for T2-wieghted MR images. To relate the outer boundary of the hyperintense region in MR images at day 4 and 45 minutes, we used a 3D geometric lesion model that was previously validated. We fit this model to the outer boundary of the hyperintense region in both MR volumes for 10 lesions. The size of the lesion boundary at 45 minutes and 4 days post-ablation were not statistically different. Therefore, we can infer that the outer boundary of the hyperintense region in the MR images 45 minutes post-ablation is a reliable marker of cell death with no evidence of cell recovery.

Discussion

Our results suggest that it is possible for hyperacute (within minutes) MR lesion image to predict the tissue response. Features such as 3D registration of in vivo MR images to histology images [4], and accurate segmentation of tissue damage boundaries on a large histology image are important steps to accurately correlate the tissue response to MR thermal lesions images. For these experiments, we determined that the outer boundary of the hyperintense region in MR images and boundary of necrosis in histology are well correlated with a mean discrepancy of approximately 1.0 mm. This value compares favorably to the MR in-plane voxel width (0.70 mm) and thickness (3.00 mm).

We conclude that our 3D methodology can be used to accurately map tissue response to MR thermal lesion images. Results show that in the rabbit thigh muscle, the outer boundary of the hyperintense region in T2-weighted MR images obtained minutes after RF ablation closely corresponds to the region of cell damage. This is good evidence that iMRI thermal lesion images can be used for feedback during thermal RF ablation treatments.

References

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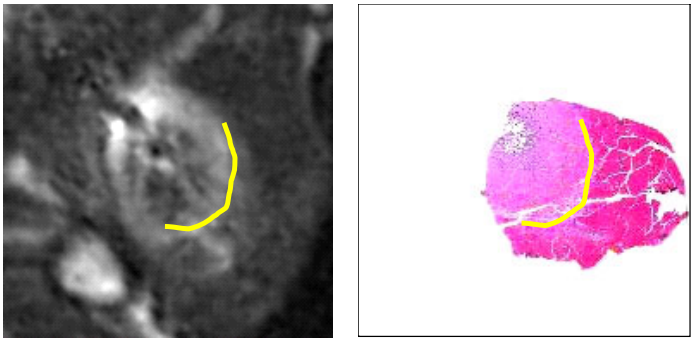

Figure 1. Hyperacute comparison of tissue damage boundary identified in histology with MR image features observed minutes after ablation. Registered images are: in vivo T2-weighted MR images (left), and Masson tricrhrome stained histology images (right) acquired minutes post-ablation. The boundary corresponds to a region of contraction band necrosis and a loss of the muscle's birefringence. Cell death boundary was marked on histology image with a graphical overlay and copied to registered MR image, where it closely corresponds to the outer boundary of the hyperintense rim.

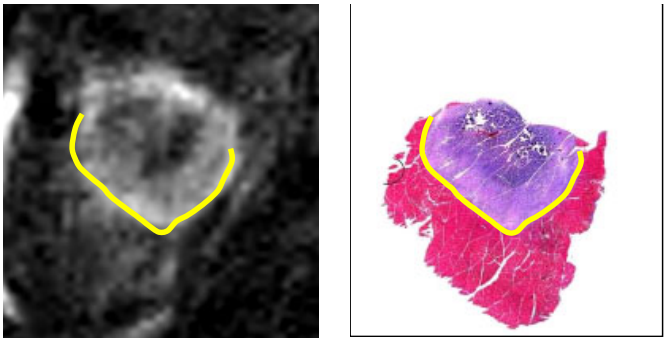

Figure 2. Subacute correlation of cell death boundary from histology with MR hyperintense rim. Registered images acquired four days post-ablation are: in vivo T2-weighted MR image (left), and Masson tricrhrome stained histology image (right). The boundary corresponds to a sharp distinct transition that separates necrotic cells from normal muscle. Cell death boundary was copied to registered MR image, where it closely corresponds to the outer boundary of the hyperintense rim.