

Assessing thermal tissue damage with biexponential Diffusion-Weighted MRI

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Introduction

Most of the prostate cancers (PCa) diagnosed at low PSA-values are unifocal, low-grade tumors. However, most current treatments for PCa are whole-gland therapies: prostatectomy or radiation for low-risk localized PCa, and radiation or hormone therapy for high-risk PCa. The side effects of these treatments are extremely common. Due to downward stage migration, interest has recently focused on developing medical devices for tumor ablation, such as cryotherapy and High-Intensity Focused Ultrasound (HIFU). MRI has a well established role in control of the treatment, due to its ability to quantify heat deposition in near real-time. MRI can additionally be used to evaluate the treatment without relocating the patient and the applicators and without involving the administration of contrast agent. DWI, in fact, is very sensitive to cell death and tissue damage [1]. In this study, we want to assess the use of DWI images to estimate prostate tissue damage during HIFU ablation, by measuring diffusion coefficients of canine prostate pre and post ablated, using multiple b-factors ranging up to 3500 s/mm².

Materials and method

A custom-made, high intensity ultrasound device operating at 7 MHz, was used to perform transurethral thermal ablation with MR thermometry based closed-loop feedback control in a GE 3T scanner. [2].

EPI DWI images were collected before and after the ablation, oblique to the prostate with b values of 0, 50, 100, 300, 500, 700, 1000, 1400, 1800, 2300, 2800, 3500 s/mm², and with a tetrahedral encoding scheme [3]. Four averages were obtained at each b value, and direction. Two ROIs were identified: a central area appearing darker on the DWI image (yellow ROI in Fig. 1) and an outer ROI appearing brighter on the DWI image (blue ROI in Fig. 1). The signal values at each b-value were fit with both monoexponential and biexponential curves. Histology with H&E was performed.

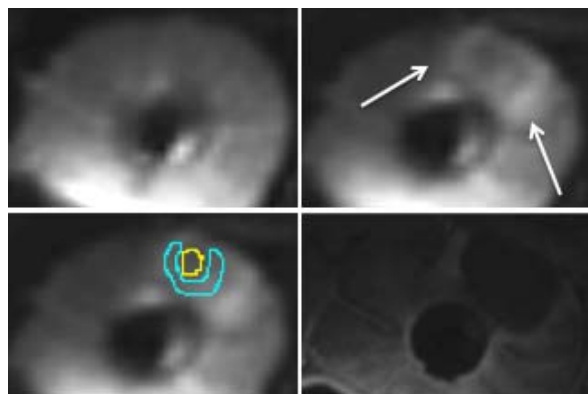


Figure 1: Upper row: on the left DWI image before ablation, and on the right DWI image after ablation. White arrows point the ablated area. Lower row: On the left, the two ROIs superimposed to the DWI image at bvalue 700; on the right Contrast Enhanced image.

coefficient decreases after ablation, with the slow component decreasing more than the fast component. The decrease of diffusion is greater in the central yellow ROI. If a single b-value is to be obtained, we find the preferred b-value to be 700, as this gives the highest CNR between ablated and unablated tissue.

Conclusion

This preliminary study demonstrates changes in the fast and slow diffusion rates and fractions after thermal ablation. In addition, differences in the diffusion rates in heat fixed vs. non-heat fixed ablated tissue are demonstrated.

Acknowledgements

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References

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Results

Histology indicated a central area of heat fixation, surrounded by coagulative necrosis without heat fixation. The SNR for all include data points was above 4.4. The biexponential model fits the data with a mean R²=0.998, thus better than the monoexponential fit (R²=0.967) (Fig. 2).

Fits are given by

Central Yellow ROI:

$$S_{pre_ablated} = 0.69e^{(0.0023*b)} + 0.28e^{(0.00040*b)}$$

$$S_{post_ablated} = 0.42e^{(0.0013*b)} + 0.55e^{(0.00019*b)}$$

Outer Blue ROI:

$$S_{pre_ablated} = 0.72e^{(0.0023*b)} + 0.26e^{(0.00042*b)}$$

$$S_{post_ablated} = 0.53e^{(0.002*b)} + 0.46e^{(0.00024*b)}$$

After ablation, there is a shift from fast to slow diffusion. In addition, each diffusion

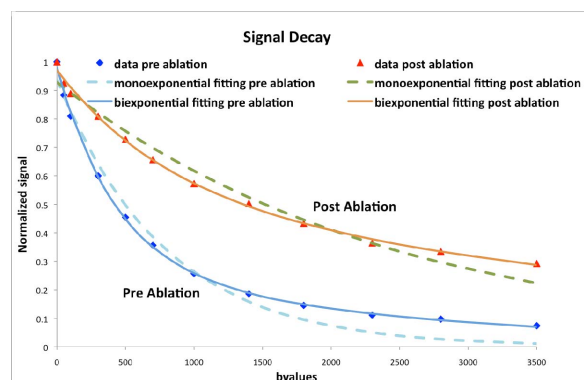


Figure 2: Pre and post ablation data, monoexponential and biexponential fitting for the ROI in the center of the ablation.