# Real-Time Interleaved Temperature and ADC Measurements For Early Assessment of Tissue Viability during Prostate Thermal Therapies

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**Introduction:** The safety and efficacy of MR-guided thermal therapies is greatly dependent on the ability to predict tissue's response to treatment. Most prediction strategies rely on indirect measures such as temperature and estimated thermal dose to infer expected tissue viability [1]. Using more physiologically relevant metrics would provide a direct measure of tissue response to treatment. Diffusion weighted MRI (DWI) has demonstrated a 36% reduction in apparent diffusion coefficient (ADC) following HIU induced tissue damage of the prostate [2]. However, using the temperature sensitivity of ADC as either a thermometry tool or to obtain an immediate map of tissue damage has been more complicated. Increasing temperature leads to an increment in ADC, but physiological effects simultaneously cause ADC to decrease. We obtained interleaved temperature and ADC measurements in order to explore the origins of the 36% reduction in ADC and whether its onset can be used for an early detection of tissue necrosis.

**Methods:** Interleaved ADC and temperature measurements were obtained during heating of *ex vivo* bovine muscle tissue initially at room temperature (Fig. 1). Heating was performed on a 3T GE MRI scanner equipped with an InSightec ExAblate 2000 HIFU system (1MHz). Temperature images were obtained using proton resonant frequency (PRF) shift measurements from a GRE sequence (TR=70ms, TE=8ms, FOV=15cm, resolution=1.17mm). ADC measurements were computed using diffusion images from three orthogonal directions using a diffusion weighted spin echo sequence (b=1000 s/mm$^2$) with a non-flyback ssEPI readout sequence (TR=1250ms, effective TE=80ms). These measurements were also obtained *in vivo* during a high intensity ultrasound treatment of the canine prostate (baseline temperature 34°C) using a customized transurethral transducer (8.73 acoustic Watts/cm$^2$, 6.8MHz (Fig. 2). Hot spot tracking was implemented to compensate for temperature dependent translations in our EPI images. Tracking was achieved by selecting the maximum value within the ROI following convolution with a Gaussian kernel. Temperature measurements were obtained by computing the mean from an ROI centered on the temperature hot spot.

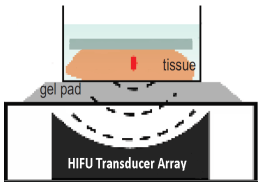


**Figure 1.** Experimental setup for *ex vivo* experiment. Tissue is submerged in degassed water. A gel pad is placed between the tissue and the transducer to improve coupling and reduce reflections.

**Results:** During the *ex vivo* experiment ADC values varied directly with temperature (2.1%/°C) regardless of thermal dose delivered to the tissue (Fig. 3a). During the *in vivo* experiment however, ADC initially increases with temperature (2.7%/°C) but stalls once the thermal dose delivered to the tissue was greater than $t_{43}$=240 min, even though the temperature was still increasing (Fig 3b). ADC temperature sensitivity for both *in vivo* and *ex vivo* experiments generally agree with previously reported values of 2.4%/°C [3].

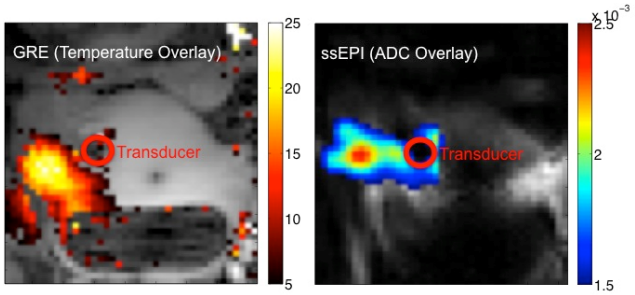


**Figure 2.** *In vivo* experiment (Left) GRE image with temperature overlay (units °C). (Right) ssEPI image with ADC overlay (units 10$^{-3}$mm$^2$/s). Distortions are due to EPI sensitivity to off-resonances. Both images correspond to the time point when ADC peaks at approximately 8 min.

**Discussion:** Variations in ADC temperature sensitivity from expected values can be attributed to differences in baseline temperatures as well as relatively large changes in temperature during the heating procedure leading to differences in the activation energy for translational molecular diffusion [3]. Future studies will terminate treatment once ADC values stop increasing with temperature to assess whether this trend can be used as an early marker for tissue viability.

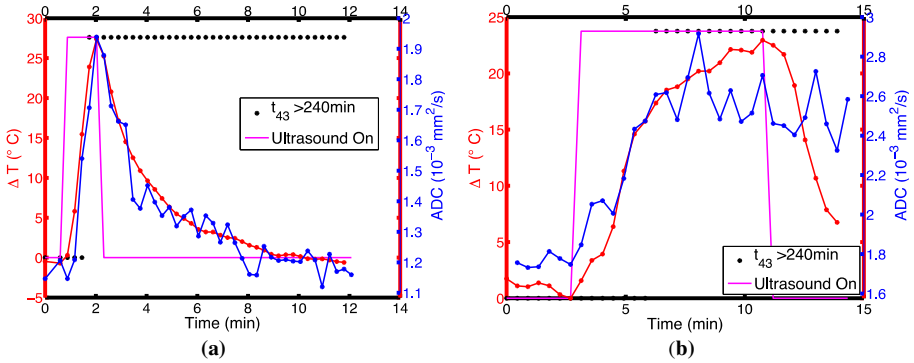


**Figure 3.** (a) *Ex vivo* and (b) *in vivo* changes in temperature (red) and ADC (blue) with application of high intensity ultrasound. Black markers indicate when thermal dose exceeds $t_{43}$=240 min.. During the *in vivo* procedure ADC values do not continue to increase with temperature once thermal dose exceeded $t_{43}$=240min.

**References:** [1] V. Rieke, K. Butts Pauly, Journal of Magnetic Resonance Imaging 2008, 27, 376-90[2] J. Chen, *et al.*, Magnetic Resonance in Medicine 2008, 59,1365-72. [3] Le Bihan, et al, Therapeutic Radiology 1989, 171, 853-57.

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