MR Temperature Mapping and Diffusion-weighted Imaging of Focused Ultrasound Surgery of Uterine Fibroids: Preliminary Study

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INTRODUCTION: Magnetic resonance (MR) guided focused ultrasound (MRgFUS) is approved by the FDA for the treatment of uterine leiomyomas, the most common solid tumors of the pelvis in women. The identification of the ablated area and the evaluation of the procedure efficiency are usually performed with T1-weighted MR imaging before and after therapy with the administration of a MRI contrast agent. However, for large ablated volumes the areas predicted by thermometry are smaller than that of non-perfused areas in contrast-enhanced T1-weighted imaging[1,2]. Other work has suggested the use of diffusion-weighted imaging (DWI) and apparent diffusion coefficient (ADC) mapping as a surrogate for contrast enhanced imaging[3]. The purpose of this work was to investigate whether changes in DWI represent regions that reached a threshold thermal dose or the resulting non-perfuse region.

METHODS: This MRgFUS study was approved by our Institutional Review Board and written informed consent was obtained before treatment. In this single center retrospective analysis, images acquired before, during and after MRgFUS of 44 adult women were analyzed. Pre- and post- treatment T1-weighted imaging using a gradient echo sequence (TR/TE: 2376/57 ms; flip angle: 30°; FOV: 20 cm; slice thickness: 5 mm) was given before and after administration of i.v. gadopentetate dimoglumine (dose: 0.1mmol/kg, Magnevist; Berlex Laboratories, Wayne NJ). T2-weighted imaging was also performed for treatment planning. Line scan diffusion imaging[4] (LSDI) was performed before and immediately after treatment (TR/TE: 2376/57 ms; b: 700 s/mm²; FOV: 28 cm; slice thickness: 5 mm). Tissue areas where the signal intensity was increased in DWI – thought to indicate cytotoxic edema[3] – were manually segmented. During focused ultrasound treatment fast spoiled gradient echo (FSPGR) images were acquired (TR/TE: 40/20ms; flip angle 30°; FOV: 28 cm; slice thickness: 3 mm). Temperature maps were obtained by exploiting the temperature dependence of the water proton resonant frequency, which was estimated using phase–difference images. Regions where the thermal dose reached values of 18 equivalent minutes at 43°C were detected and the areas were calculated[1]. Thermal dose estimates and DWI areas were compared with the non-perfused regions segmented on contrast enhanced MR images (Fig. 1). Comparisons were all made in a single coronal imaging plane. In all cases the ExAblate 2000® MRgFUS device (InSightec, Haifa, Israel) in combination with a 1.5T MRI unit (GE Healthcare, Milwaukee, WI) was used.

RESULTS: As previously reported[1], the thermal dose estimates correlated well with the non-perfused areas for small ablated volumes, but underestimated this area for large treatments (slope: 2.5 ± 0.4, y_{int}: -3.9 ± 6.1 R=0.72). DWI areas showed a similar pattern (slope: 1.73 ± 0.30, y_{int}:2.9 ± 5.0, R=0.72). High signal regions in DWI showed good correlation with the thermal dose estimates (slope: 1.1 ± 0.2, yint: 0.9 ± 2.4, R=0.74), independently of the size of the ablated volume. However, in 14 cases no changes to signal intensity was observed in DWI, and in general the image quality was relatively poor. The data for the 30 cases where DWI changes were seen is summarized in Graph I.

DISCUSSION: This data suggests that changes in DWI represent regions that reached a lethal thermal dose, not the regions that become non-perfused after the treatment. As observed earlier, these non-perfused areas were often larger than the thermal dose prediction, especially for larger treatments[1, 2]. Even though changes were not clearly seen in every case, this DWI sequence appears useful for finding the thermally-ablated regions without resorting to the use of contrast. This ability is helpful for treatment planning after patient motion during a treatment or for a second MRgFUS treatment. Optimization of the DWI parameters might allow for this detection with more reliability. The flexibility and improved motion sensitivity of the line scan acquisition appear to be well suited for this application.

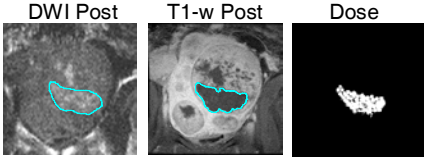
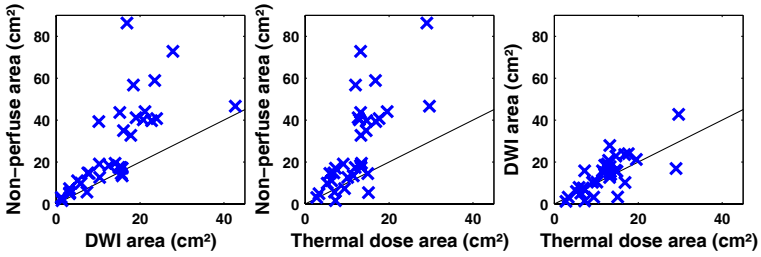


Figure 1: Coronal DW and T1-weighted contrast enhanced images post treatment and thermal dose of 18 equivalent min at 43°C.



Graph I: Scatter plots illustrate comparison between the area of non-perfused regions, thermal dose estimates and DWI. (solid line: unity)

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