Real-time Quantitative Treated Volume Estimation in MR guided FUS Uterine Fibroids Surgery

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Introduction: Non-invasive treatment of uterine fibroid tumors is highly desirable and provides an alternative to surgery. Uterine fibroids are benign (non-cancerous) tumors, which grow within the muscle tissue of the uterus. Magnetic resonance guided focused ultrasound (MRgFUS) uses on-line MR temperature monitoring of an outlined volume that is thermally ablated with ultrasound waves focused through the intact anterior abdominal wall. Recent publications have demonstrated the use of diffusion weighted imaging (DWI) for identification of ablated uterine fibroids region [1-2]. Currently, Contrast enhanced (Gd-DTPA) T1-weighted imaging (CE-T1W) is the gold standard to assess the treatment of uterine fibroids with MRgFUS [3]. CE-T1W MR images are useful to detect necrosis after treatment. In this study, our purpose was to develop an alternative non-contrast method based on contrast enhancement by adaptive histogram equalization and K-means clustering segmentation technique for providing on-line quantification of necrosis volume without using contrast agent and resultantly the precise end-point of the FUS ablation.

Materials and Methods: Ten patients with symptomatic uterine fibroids, who underwent treatment with MRgFUS (ExAblate 2000 system, InSightec co, Israel), were included in this study. The studies were performed on a GE Echo Speed Excite 1.5T scanner (Milwaukee, WI). Diffusion-weighted MR images were obtained before and after FUS treatment (b=0 and 500 sec/mm^2, FOV 38cm, 7mm slices, matrix 128x160, TR/TE 4000/69.5ms, BW 169kHz, NEX=7). Following the treatment, anatomical MR images are used to evaluate treatment outcome. CE-T1W MR images were also acquired for verification of the ablated region. The patients were clinically monitored throughout the acquisition of the images.

Data Analysis: Real time MR image analysis was conducted on a windows-based PC (Dual processor Pentium IV, 3.2 GHz, Windows 2000 OS) connected to the GE MR scanner. First, contrast enhancement by adaptive histogram equalization, which uses the histogram equalization mapping function supported over a certain size of a local window to determine each enhanced density value, was applied into the final DW images (b=500) to enhance the heated region in each slice in the series. Second, K-means clustering was applied into enhanced DW images to segment the ablated region. In this procedure, the objects are randomly assigned to one of the K-clusters. Once this is done, the position of the K-centroids is determined. A global optimization method is then used to reassign some of the objects to different clusters. This procedure is continued until the optimum assignment of objects to clusters is found. Third, morphological operations were applied to segment the enhanced region and remove the image background and other unwanted structures. Finally, all enhanced DWI image volume was co-registered and realigned to the CE-T1W imaging volume with SPM2 [4] before estimating the ablated volume of uterine fibroids.

Results: In most cases, the shapes of enhanced regions in the enhanced DWI and CE-T1W images were similar. Considerably increased signal intensity changes that were localized within the treated areas were noted on DW images. Figure 1 shows 12 slices (s_1-s_{12}) of DWI (rows 1-2) and enhanced DW (rows 3-4) images of a final time frame on a 44 yo patient. Similarly, Figure 2 shows the extracted boundary overlayed with DW (rows 1-2) and CE-T1W (rows 3-4) images. Total treated uterine fibroids volume based on enhanced DWI and CE-TWI was 179 and 191cc, respectively. The volume (v) of treated uterine fibroids were calculated by the equation $v=4/3\ \pi \times a \times b \times c$, where a, b and c are the diameter of enhanced region in x and y direction, the total slice thickness between first and last enhanced slices, respectively.

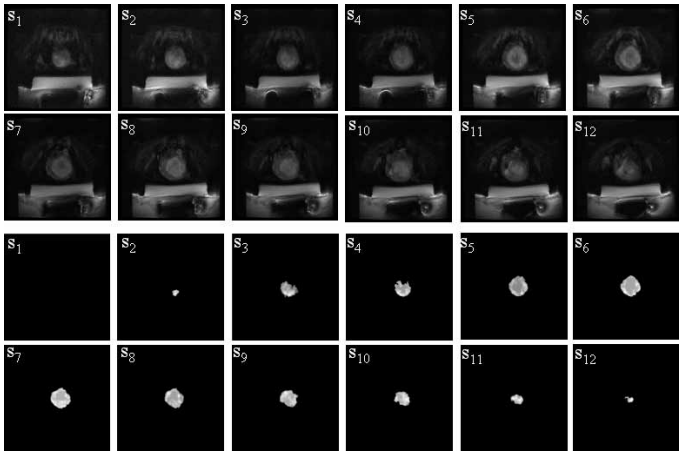

Figure 1. Rows 1-2: The 12 out of 18 slices (s_1-s_{12}) of diffusion- weighted images. Rows 3-4: The corresponding slices of enhanced diffusion weighted images.

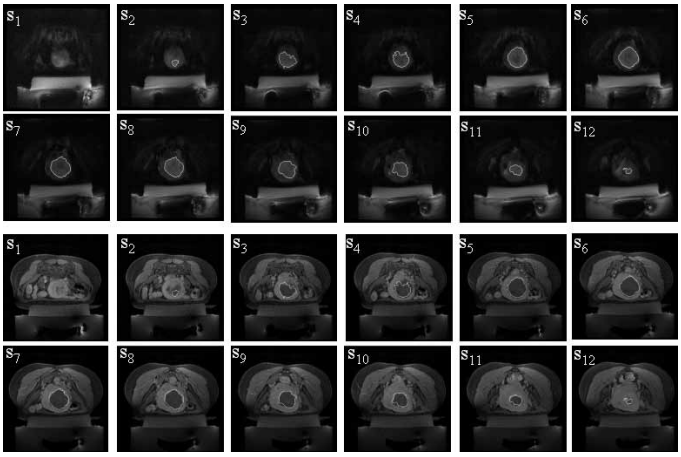

Figure 2. Rows 1-2: The 12 out of 18 slices (s_1-s_{12}) of extracted boundary overlayed with diffusion-weighted images. Rows 3-4: The corresponding slices of extracted boundary overlayed with CE-T1W images.

Discussion: Our initial results indicate that it is possible to provide on-line quantification of necrosis volume without using contrast agent and resultantly the precise end-point of the FUS ablation. However, the applicability to all clinical uterine fibroids cases must be examined further

References [1] Jacobs MA, Radiology. 2005; 236:196-203 [2] Liapi E, JCAT. 2005; 29:83-86 [3] Tempany CM Radiology2003;226:897-905 . [4] http://www.fil.ion.ucl.ac.uk/spm