Evaluation of “referenceless” thermometry in MRI-guided focused ultrasound surgery of uterine fibroids

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Introduction: Recently, a method for MRI-based thermometry that uses the temperature dependence of the water proton resonant frequency (PRF) shift was described that uses single phase maps instead of phase-difference images (1). This method could make MRI-based thermometry less motion sensitive by removing the misregistration errors in phase-difference imaging. The purpose of this work was to test the accuracy of this method, termed “referenceless” thermometry, during MRI-guided focused ultrasound surgery (MRgFUS) of uterine fibroids. The temperatures measured with this method (T_R) were compared with the standard phase-difference technique (T_P) (2).

Methods: For “referenceless” thermometry, an unheated region in the phase maps is chosen surrounding the heated area. The (unwrapped) phase in this area is fit to a polynomial surface to estimate the phase within the heated area, which is subsequently subtracted off, leaving behind only the effects due to the heating. The order for the polynomial fit is determined by testing different order fits in a baseline (unheated) image and choosing the order that minimizes the error in area to be heated. Temperature images (time series of spoiled gradient echo images in a single plane on a 1.5 T scanner with TR/TE: 40/20 ms, flip angle: 30°, field of view: 28cm, matrix: 256×128, bandwidth: 3.6 kHz, slice thickness: 3mm) were chosen from a pool of 50 patients treated with MRgFUS using the ExAblate 2000™ device (InSightec, Haifa Israel) (see (3-5) for details). One hundred sonications (from 33 patients) were randomly selected that were more than 3 cm away or delivered 5 min after a previous sonications so that residual heating was not present in the area that was fit. Since the fibroids are mostly stationary during the treatments, the phase-difference images generally did not have motion-induced errors and when directly compared voxel by voxel with the “referenceless” method served as a gold standard measurement. We tested the agreement between the two techniques and calculated the error in the fits to the baseline. Thermal dose (6) contours were also generated and compared. Regions with dimensions of 21×21 voxels (coronal, perpendicular to the ultrasound beam) or 21×61 voxels (sagittal, parallel to beam direction) were chosen for the heated regions; an 11 voxel wide strip surrounding these regions was chosen for the fitting. Regions that were outside the fibroid and those containing large blood vessels were excluded by manual segmentation.

Results: The average value of T_R in the baseline images (no heating) was -0.2 ± 0.5, indicating a good fit, and the average standard deviation was 1.7 ± 1.6, which is less what was observed in T_P (standard deviation 2.9°C). The difference between T_P and T_R varied for different sonications (Fig. 1), but in general was good. The average difference between measurements was less than 3°C in 92% of sonications. The average difference, standard deviation, slope, y intercept, and correlation coefficients for the comparisons were 0.6 ± 2.0, 2.2 ± 0.9, 0.95 ± 0.08, 0.94 ± 0.05. A few cases could not be fit well, and were typically either those with large flow artifacts, those with only small areas outside of the heated zone that were in the fibroid, or those in areas with exceptionally large susceptibility artifacts. In a few cases, motion artifacts were evident in T_P. These artifacts were not evident in T_R. The appearance of the heating and thermal dose (6) contours created with both methods agreed well (Fig. 2), with those created from T_R having less apparent noise.

Discussion: The “referenceless” method appears to be adequate for temperature monitoring of MRgFUS in fibroids. Manual removal of areas outside the target organ and those containing large blood vessels was time-consuming, and could limit the usefulness of the method unless robust automatic methods can be developed. It appears that in a small number locations it will not be possible to apply this method due to a lack of sufficient unheated areas outside the heated zone or large susceptibility-induced artifacts. Overall, this data is encouraging, since the fibroids are similar to other common targets for thermal ablation (liver, kidney) in that they are deep targets and neighbored by bowels, which create large magnetic field (and thus phase) gradients due to susceptibility effects.

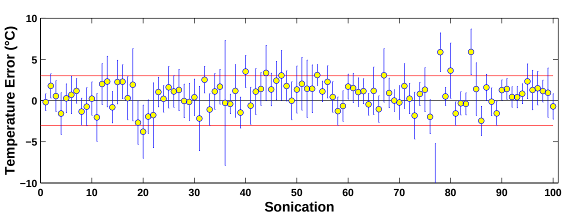

Fig. 1: Plot of average difference between T_R and T_P for 100 sonications in uterine fibroids. Large error bars indicated poor fits, and shifts from zero often indicated motion artifacts in T_P. Horizontal lines show 0 and ± 3°C error.

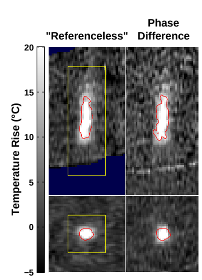

Fig 2: Examples of T_P and T_R for two sonications in uterine fibroids. The box in the T_R images is the region that was fit. The solid area in the image was not included, since it was outside the fibroid. Thermal dose contours created by the two methods (240 equivalent min at 43°C) are superimposed. Top: image acquired parallel to the direction of the ultrasound beam; bottom: image acquired parallel to the beam direction.

References

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