Prior Baseline Thermometry for Improved Thermal Dose Prediction in MRgFUS of Soft Tissue Tumors

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Background

MRI proton resonance frequency shift (PRF) thermometry is widely used to monitor tissue temperature during MR guided focused ultrasound ablation (MRgFUS). Temperature maps are used during the treatment to determine areas that reached lethal thermal dose. Treatment efficacy is quantified immediately after treatment by measuring the non-perfused volume (NPV) of contrast-enhanced (CE) images. However, previous studies in uterine fibroids[1] have shown that conventional PRF thermometry thermal dose volume under-predicted treatment when compared with NPV (Fig 1). The purpose of this work was to investigate how much of the under prediction was due to errors in thermometry due to an assumption of the return to baseline temperature. We propose the use of a prior baseline method of PRF thermometry to better predict treatment dose volume during a MR-FUS treatment.

Methods

MR-HIFU treatment was performed in a GE 3T scanner using the InSightec ExAblate 2000 system. Eighty seven sonications (1.1 MHz, 20s, 500 J– 1300J) were delivered to a patient with a soft tissue tumor located in the right buttock, using general anesthetic. The thermometry sequence was a 2DFT SPGR (TE/TR =12ms/25ms, SlTk=5mm), acquired every 3 seconds. CE images were acquired immediately following the treatment using a 3D GRE with fat suppression (LAVA, GE, TE/TR=1.7ms/5.4ms, SlTk=3mm).

The prior baseline method searches the previously acquired sonication baseline images for a match. Criteria for prior baseline similarity match include: 1. 2D normalized cross correlation of magnitude images to check for motion, 2. Magnitude weighted mean of the phase difference images between prior and immediate baselines to check for large phase difference errors. If no appropriate prior baseline is found, the immediate baseline image is used. Thermal dose area was calculated using the 43°C or 240 CEM criteria[2], and multiplying by the slice thickness for dose volume per image slice. Dose contours overlays (Fig 1, red) indicate only those pixels that met or exceeded the lethal threshold.
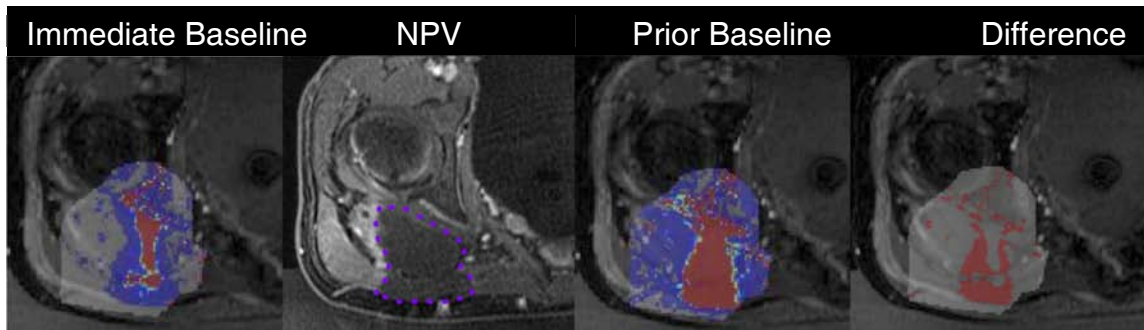

Figure 1. a) Magnitude image with immediate baseline thermal dose overlay. Gray overlay is region of treatment. Red is lethal dose contour. b) Post treatment contrast enhanced image of similar slice showing non-perfused volume (purple dotted line). c) Magnitude image with prior baseline dose d) difference between immediate and prior baseline.

Results

The prior baseline method estimates a larger treatment volume than was calculated using immediate baselines (Fig 1). The progression of dose volume over the course of the treatment is seen in Fig 2. The prior baseline approach shows greater dose volume than the immediate baseline volume, with the deviation between the two increasing over time. The total dose volume estimates were 51 cm^3 for immediate baselines, 85 cm^3 for prior baselines, and 91 cm^3 from NPV.
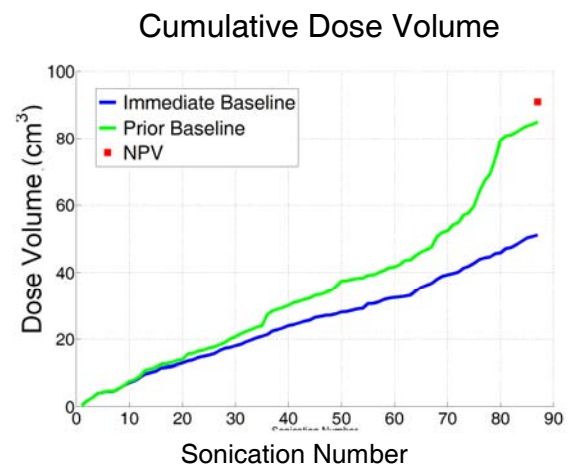

Figure 2. Comparison of cumulative dose volume over the course of the treatment using immediate and prior baseline approach.

Discussion

With similar sonication energies, the immediate baseline approach assumes a starting temperature of 37°C for each new sonication, and dose increases linearly. However, using prior baselines shows a non-linear accrual of dose, suggesting a local elevation of base temperature, and lack of cooling between sonications. While the prior baseline approach yielded a larger total treatment volume, it was still less than the NPV. However, 39% of the sonications did not have a matched prior baseline, and instead used immediate baselines for measurements. If there had been baselines early in the treatment to match each sonication, it could have contributed to additional dose, and better agreement between the NPV and the estimated dose volume. Acquiring a pre-treatment library of all possible baselines so that all images acquired during treatment have a prior baseline could further improve thermometry dose prediction. Improving the thermometry would allow a better estimation of how much of the mismatch is due to other factors such as post treatment swelling.

Conclusion

In treatments when tissue has not fully cooled to pre-treatment temperatures between sonications, error from assuming that the immediate baselines are at 37°C causes thermal dose volume to be under-estimated. The use of prior baseline thermometry yielded thermal dose volume predictions that were more similar to post treatment CE non-perfused volume than the immediate baseline method.

References [1] Hindley J, et al, AJR. 2004, 183(6):1713-1719. [2] Sapareto S, et al. Inter J of Rad Onc Bio Phys. 1984, 10(6):787-800.