Title: Importance of T2 Correction in Intravoxel Incoherent Motion (IVIM) based Quantitation of the Necrosed Region Post Thermal Ablation of Uterine Fibroid

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Introduction: MR guided HIFU based thermal ablation is a non-invasive therapy for treatment of uterine fibroid[1]. Typically, non-perfused volume (NPV) in post-contrast T_1 weighted MR image is used to quantify the HIFU induced tissue necrosis. However, a non-contrast based MR method, if available, would make it possible to monitor the evolution of necrosis *during* treatment and may also aid in patients at risk for developing nephrogenic systemic fibrosis (NSF) due to MR contrast. Some groups have proposed the use of intra voxel incoherent motion (IVIM) model[2] to estimate the blood volume fraction (*f*) as a surrogate for NPV[3]. Studies have shown that the T2 of the underlying tissue can influence the estimation of f value in bi-exponential fitting of IVIM[4]. This is of particular concern in using IVIM model to estimate f in HIFU therapy, as the T_2 of tissue will be prolonged in the aftermath of HIFU therapy, compared to untreated tissue. We hypothesize that T_2 corrected *f*-map will correspond more closely to tissue damage as assessed by thermal dose maps.

In the previous study, we reported that f map of uterine fibroid generated by asymptotic fitting. To test the hypothesis, in this pilot study, T_2 correction for asymptotic fitting for IVIM model has been performed and (1) the f map compared with and without T_2 correction for the whole fibroid, and (2) f map and perfusion coefficient (*D**) with/without T_2 correction compared with thermal dose map.

Methods: In this IRB approved study, all the images were acquired in 1.5T scanner (Philips, Achieva 1.5T). During HIFU therapy, temperature was monitored in real-time by multi-slice (M2D) GRE-T_1 weighted EPI sequence with the following parameters: TR/TE: 38/20ms, EPI factor: 11; acquired voxel size: 2.5x2.5x7mm^3; temporal resolution: 3s. Around 10 minutes after HIFU treatment, T_2 map, and DWI were acquired with the following parameters: (1) T_2 map: turbo spin echo sequence (TSE) with 12 echoes was used with TR/TE/ΔTE: 2000/12/12 ms; acquired voxel size: 3x3x5mm^3; scan time: 3:12min. (2) DWI: single shot SE-EPI sequence with TR/TE: 2500/69 ms; half scan factor: 0.717, SENSE factor: 2; b = 0, 10, 20, 40, 60, 200, 450, 900 s/mm^2; acquired voxel size: 3x3x5mm^3; scan time: 2:38min.

Data Analysis: All processing was done offline using custom-written software in MATLAB™. Pixel wise f map and D map without T_2 correction were generated by IVIM model associated with asymptotic fitting using three highest b values and b = 0. Pixel wise D* map was generated by the IVIM model associated with bi-exponential fitting using five lowest b values and f, D maps obtained earlier. Mean T_2 values of non-treated region (51ms) and treated/necrosed region (68ms) of the fibroid were obtained. T_2 of blood is assumed to be 290ms at 1.5T.[5] T_2 corrected f maps were calculated using Eqn. 2.T_2 correction for D* map was generated by the method reported by Lee et al. [4]. Thermal dose volume (TDV) map (the pixels with thermal dose >240EM at 43˚C) were generated from the temperature evolution during heating. The concordance between the TDV map and f-map was assessed by the Dice ratio.

$$s(b) = s_{int}e^{-bD} \quad (b = 200, 450, 900\ s/mm^2) \qquad (1)$$

$$f = \frac{(s_1 - s_{int})e^{-\frac{TE}{T_{2tissue}}}}{\left(e^{-\frac{TE}{T_{2blood}}} - e^{-\frac{TE}{T_{2tissue}}}\right)s_{int} + s_1 e^{-\frac{TE}{T_{2tissue}}}} \qquad s_1 = s(b = 0) \qquad (2)$$

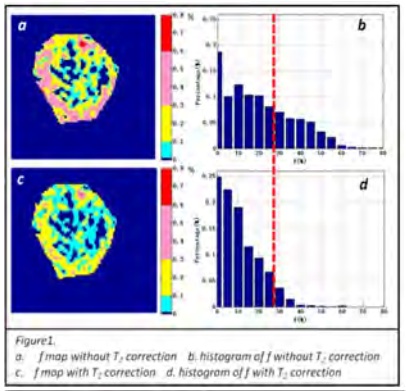

Figure1.
a. f map without T_2 correction b. histogram of f without T_2 correction
c. f map with T_2 correction d. histogram of f with T_2 correction

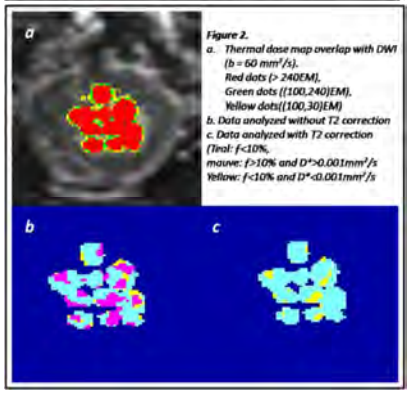

Figure 2.
a. Thermal dose map overlap with DWI (b = 60 mm²/s).
Red dots (> 240EM),
Green dots ([100,240]EM),
Yellow dots([100,30]EM)
b. Data analyzed without T2 correction
c. Data analyzed with T2 correction
(Teal: f<10%,
mauve: f>10% and D*>0.001mm²/s
Yellow: f<10% and D*<0.001mm²/s

Results: Without T_2 correction 30% of the pixels in the whole fibroid had f >30%, and with T_2 correction only 10% pixels had f >30% (marked by red dot line in Fig.1b and d). In Fig.2 f and D* maps without (b) and with (c) T_2 correction are overlaid on the thermal dose map. All the pixels in thermal dose map with f <10% or D*<0.001mm^2/s were classified as pixels equivalent to NPV. Before T_2 correction, 29% pixels with thermal dose >240EM had f>10% and D*>0.001 (high perfusion, marked as mauve in Fig.2b), after T_2 correction, all these pixels had f<10% or D* < 0.001 (low perfusion, marked as teal and yellow in Fig. 2c).

Discussion: The f map was reported as a new method to estimate the treated region in MRgHIFU therapy of uterine fibroid.[3] It showed a high dice similarity between the low f (<10%) region and the NPV from CE image. The results reported from this study suggest the importance of the T_2 correction of IVIM model analysis for treatment result estimation. T_2 of the necrosed region is different from the non-treated region, and both of them are significantly shorter than the T_2 of blood. Thus f both necrosed and non-treated region decreases after T_2 correction. The regions treated with thermal dose >240EM but showing high perfusion without T_2 correction show decrease after T_2 correction.

Conclusion: T_2 correction in IVIM model based computation of perfusion is critical in improving the accuracy of the quantification of the necrosed region post thermal ablation.

Reference:

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