# Proton Resonance Frequency Shift Weighted Imaging for the MR monitoring of the thermotherapy

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## Introduction

Recent development of MRI-guided focused ultrasound (MRIgFUS) technology has been demonstrated the potential as a non-invasive surgical tool in many clinical settings [1].Among the MRI methods, the PRF temperature mapping is the most popular for this purpose due to its linearity, sensitivity, and near-independence of tissue type [2]. It is generally accomplished by acquiring spoiled gradient-echo sequences and transforming the obtained phase images into quantitative temperature maps [2].In addition, the magnitude images obtained in the meantime can allow the anatomical identification and also the lesion localization. Owing to the temperature dependence of most MRI parameters such as the longitudinal relaxation time T1 [3] and the proton density [4], the magnitude images obtained by the PRF-based sequences also exhibit temperature-related image contrast. In this study, we aimed to fuse the temperature-dependent phase and magnitude image by a post-processing method similar to the recently advanced susceptibility-weighted imaging (SWI) method, namely PRFSWI.

## Theory

According to the past studies, the proton density (PD) is proportional to 1/T ~0.3%/$^o$C to ~0.7%/$^o$C [4]. On the other hand, the temperature dependence of the relaxation time T1 is on the order of 1%/$^o$C[3]. While the local temperature is elevated by HIFU heating, the PD reduction and the prolonged T1 (due to temperature elevation) both contribute to the signal drop at the heated region. In addition to the magnitude drop, the PRF shifts to a lower value while the temperature is elevated. Interestingly, the overall temperature-dependent signal behavior (both magnitude and phase) is very similar to the blood oxygen-level dependent effects of the venous blood vessels [5] except the sign of the off-resonance frequency change (SWI: the more deoxyhemoglobin, the higher PRF; PRFSWI: the higher temperature, the lower PRF)

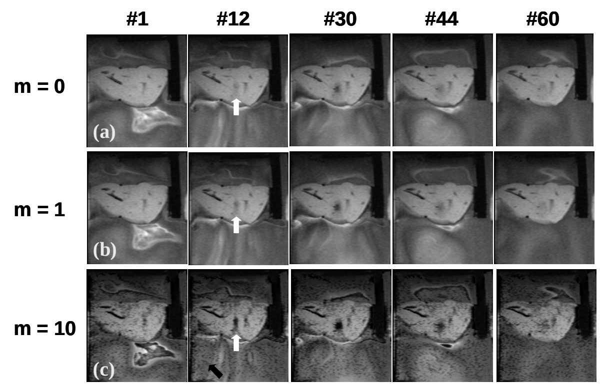


**Figure 1:** (a) m=0, original magnitude images, (b) m=1, (c) m=10. Notice that the heated spot (white arrow) can be clearly observed in PRFSWI (b,c) images at the initial stage of HIFU heating.

## Materials and Methods

PRFSWI post-processing was almost identical to the SWI method with the modification of the phase-mask scaling. Due to the sign reversal of the temperature-dependent PRF shift, the phase-mask of PRFSWI was modified as follows:

$$PM(x,y) = \frac{\pi+\theta}{\pi} \text{ if } \theta<0, \quad PM(x,y)=0 \text{ if } \theta \geqq 0$$

Pulsed-wave HIFU pulses with power of 83 watt were performed on porcine liver tissue, immersed in 25℃ degassed water. Serial MR images were acquired on a 3T clinical imager (Siemens Trio, Erlangen, Germany) with the gradient-echo sequence(TR/TE:2.9ms/3.61ms, flip angle:20° , FOV: 160×120mm$^2$ , matrix size:128×96, slice thickness:3mm, dynamic number:40, HIFU ON/OFF: OFF (0~19 sec), ON (20~122 sec) , OFF (123~223 sec)). The acquired images were transferred to a personal computer for the PRFSWI processing with Matlab® system (Mathworks, Natick, MA, USA).

## Results

Fig.1 shows the selected PRFSWI images (multiplication factor m: 0,1,10) acquired during HIFU transmission. Note that the contrasts of the heated-spot (indicated by white arrows) increases while m-factors are higher. Fig.2 shows the quantitative curves of the averaged signal intensity and the temperature of a ROI covering the heated spot. We can notice that the signal drop of PRFSWI (m=10) is more prominent than that of the original magnitude images.

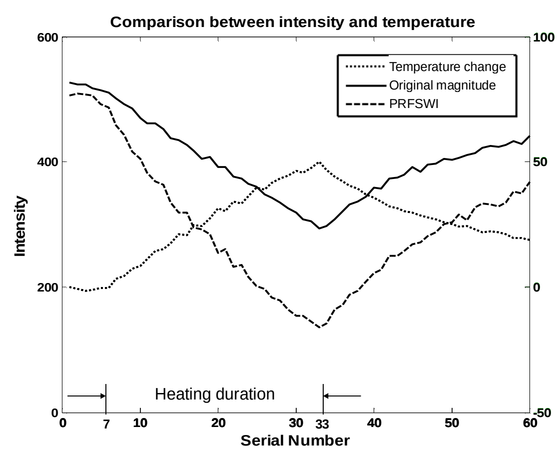


**Figure 2:** The signal intensity and temperature change (dotted line) of dynamic curves are ROI of heated spot of original MR gradient echo image (solid line) and PRFSWI image (dashed line).

## Discussion and Conclusions

In our results, the PRFSWI method enhanced the temperature-related contrast during HIFU transmission. The raised contrast is helpful to identify focused spot during the pre-treatment procedure. After applying PRFSWI enhancement, the image contrast is significantly improved. For the HIFU monitoring applications, the PRFSWI technique combined with the optimized m factor can be applied to enhance the visibility of the target spot. It is very helpful for treatment planning and calibration. Compared to the PRF-shift temperature quantification, PRFSWI does not need the baseline subtraction. Therefore, the problem of motion-induced subtraction error can be avoided in PRFSWI method. Moreover, the PRFSWI post-processing is fully compatible to the temperature mapping sequence. Neither sequence modification nor the parameter adjustment is required. Therefore, the PRF-shift thermometry and the PRFSWI can be obtained simultaneously to improve the treatment accuracy. In conclusion, PRFSWI method ,which enhances the image contrast around the heated tissue by fusing the magnitude image and the modified phase data, can be a practical tool for real-time monitoring the HIFU treatment process.

## Reference

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