# Referenceless PRF thermometry with multi-echo processing

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**Introduction** Referenceless proton resonance frequency (PRF) shift thermometry [1] is inherently robust to tissue motion because the subtraction of a baseline phase image acquired prior to heating is not necessary. Instead, the background phase is estimated in every individual image from a frame region of interest (ROI) surrounding the heating region. For thermal monitoring during prostate ablation, we have proposed an extension to referenceless thermometry [2] that allows temperature estimation in the presence of phase discontinuities between water and fat. The necessary three echoes for this method were acquired in two separate acquisitions.

Here, we propose a pulse sequence where all three echoes are acquired in a single acquisition for increased temporal resolution of the temperature monitoring during thermal ablation. It has been shown that due to the relatively low spatial resolution of the heating distribution it is sufficient to acquire a low resolution image for temperature monitoring (1.7-1.9 mm in plane) [3]. To visualize the anatomical structures, however, higher resolution is desired. In the proposed pulse sequence, each echo's k-space coverage varies in order to allow reconstruction of both a low resolution temperature image and a high resolution anatomical image, without a decrease in temporal resolution. The method is demonstrated in phantoms and during *in vivo* canine prostate ablation.

**Methods** In the new pulse sequence shown in Fig. 1 three echoes are acquired in a single acquisition with echo times (TE1=14.3, TE2=21.4, TE3=28.6 in ms) corresponding to phase angles between water and fat of $2\pi$, $3\pi$ and $4\pi$ at 0.5T. The low resolution, full k-space data is used for a Dixon decomposition to create binary water/fat masks for the phase estimation and to generate a combined temperature map from all three echoes as described previously [2]. To create a high resolution magnitude image, the asymmetric k-space data from the first and third echo is reconstructed by zeropadding to center the echo in k-space and averaging the resulting magnitude images. The high resolution magnitude image is then used as the background for the color overlay of the temperature data.

Images were acquired in phantoms and during thermal ablation of the prostate in a canine model using a transurethral ultrasound transducer [4] on a 0.5T scanner (Signa SP, GE Healthcare, Milwaukee WI). Additional imaging parameters were TR/BW/flip/FOV/slice = 150 ms/16 kHz/60/16×12 cm/5 mm, the low resolution, symmetric imaging matrix was 96×96, and the total imaging matrix for 1st and 3rd echoes was 176×96. To demonstrate the robustness to tissue motion, pressure was applied to the animal's abdomen before heating started.

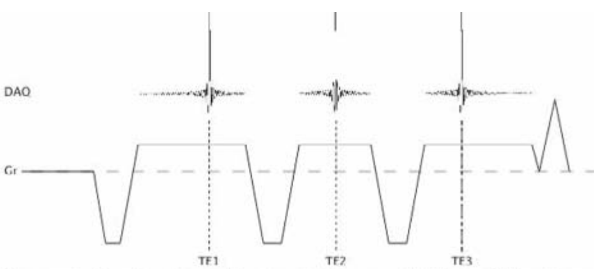


**Figure 1: Readout gradient and data acquisition of the three echo gradient echo sequence.**

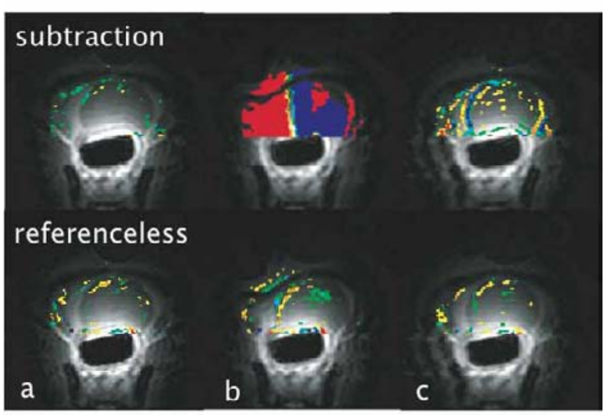


**Figure 2: Temperature images acquired during preheating comparing referenceless reconstruction and baseline subtraction. When tissue motion occurs (b), severe errors render baseline subtraction useless.**

**Results** Figure 2 shows images of the canine prostate acquired with the proposed pulse sequence. Temperature overlays of three preheating images are shown, comparing referenceless reconstruction and baseline subtraction. Without tissue motion (a), both temperature images are similar. When motion occured (b), images reconstructed with baseline subtraction did not provide any useful temperature information, whereas images reconstructed with referenceless reconstruction have little artifacts. After the motion (c), an artifact remains in the baseline subtraction images, because the prostate did not return to its original position.

Measuring the temperature uncertainty of the combined temperature map of the three echoes showed that averaging the three echoes compensates for most of the signal decrease due to the higher bandwidth in the individual echoes. The temperature uncertainty was comparable with that of a single echo sequence longer readout time.

**Discussion** The new pulse sequence allows for acquisition of all three echoes necessary for the Dixon decomposition in a single acquisition. All three echoes are used to generate a low resolution temperature map compensating the decreased SNR due to the higher bandwidth of the individual echoes. Because the spatial variation of the temperature distribution is low compared to the anatomical structures, a low resolution temperature map is sufficient to depict the heating area. Using the additional, asymmetric k-space data from the first and third echo allows a high resolution magnitude image to be generated, which depicts the anatomical features and is used to overlay the temperature map. If reconstruction speed is not critical (e.g. for retrospective reconstruction), even higher resolution can be achieved with a partial k-space reconstruction technique such as POCS or homodyne.

**References** [1] Rieke V. et al. Magn Res Med. 51(6), 1223-31 (2004) [2] Rieke V. et al. Proc. ISMRM, 2004.
[3] Pisani, L.J. et al, J. Magn Reson Imaging 22(1):109-18, 2005. [4] Kinsey A.B. et al. Med Phys. in print.

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