Modified EPI sequence for improved MR thermometry

B. Madore[1], R. Chu[1], C-S. Mei[1], J. Yuan[2], T-C. Chao[1], and L. P. Panych[1]
[1]Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA, United States, [2]Department of Imaging and Interventional Radiology, the Chinese University of Hong Kong

Introduction: An MR thermometry sequence and reconstruction procedure is proposed here, which offers advantages in terms of temperature-to-noise-ratio (TNR), tissue contrast and temperature accuracy. An interleaved EPI sequence, frequently used in proton-resonant-frequency (PRF) thermometry [1,2], was modified as depicted in Fig. 1. While an EPI train samples the gradient-echo (FISP) signal as usual, the early part of TR is utilized to sample the spin-echo-like PSIF signal as well. 'Superblips' along G_z, shown shaded in Fig. 1, allow one to move from FISP to PSIF signal. Sampling both PSIF and FISP, as opposed to only FISP, proves advantageous.

Theory: With N_s the number of shots in an interleaved-EPI sequence, scan time is given by $N_s\times$TR. During this time, the sequence in Fig. 1 acquires both a PSIF and a FISP image instead of only a FISP one. Both images offer good sensitivity to temperature changes as the PSIF has maximum temperature sensitivity at short TE, while the gradient-echo FISP has maximum sensitivity at longer TE values [3,4]. Three main advantages come from having the PSIF results as well: 1) Independent PSIF- and FISP-derived temperature curves can be combined, thus improving temperature-to-noise ratio (TNR). 2) The two image types offer different contrasts, and comparing them makes it easier to detect blood vessels for motion-tracking purposes, or to detect T_2 changes resulting from thermal damage. 3) Comparing PSIF- and FISP-derived temperature measurements allows one to correct for errors that might otherwise remain undetected, thus improving temperature accuracy. For example, susceptibility effects may shift signal in k-space, changing which echo in the EPI train happens to sample peak signal, affecting the value of effective TE. With $T_{PSIF}(t)$ and $T_{FISP}(t)$ the PSIF- and FISP-derived temperature curves, and using scan parameters TR, TE_{PSIF} and TE_{FISP}, the shift ΔTE can be obtained by solving:

$$\Delta TE\times(T_{PSIF}(t)(TR-TE_{PSIF})+T_{FISP}(t)TE_{FISP}) = TE_{FISP}\times(TR-TE_{PSIF})\times(T_{FISP}(t)-T_{PSIF}(t)).$$

The solution for ΔTE can be used to correct the nominal TE values. More accurate temperature curves are calculated, where $(TE_{FISP}+\Delta TE)$ and $(TE_{PSIF}+\Delta TE)$ replace TE_{FISP} and TE_{PSIF}, as image phase gets converted into temperature.

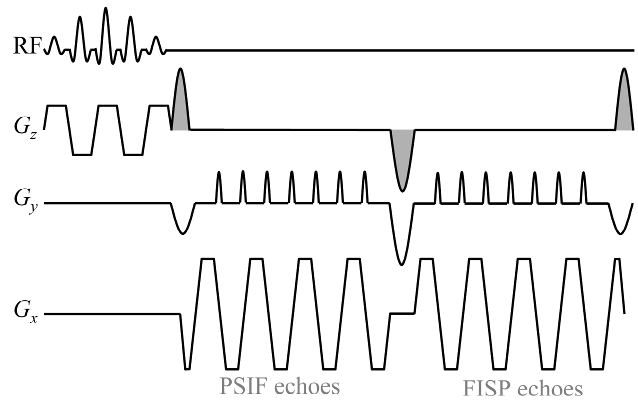

Fig. 1: *The sequence proposed here is an interleaved-EPI sequence that samples both a FISP and a PSIF signal.*

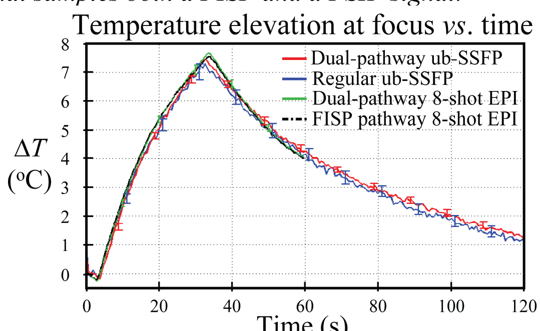

Fig. 2: *Tested methods gave similar temperature values, but different noise values (error bars).*

Results: 1) TNR. The proposed method was used to monitor ultrasound-induced heating in a gel phantom (GE 3T system, TR=34ms, 8 shots, frame rate=3.7fps, 128x96, 24cm FOV, 5mm slice, regular sinc-like RF pulse). For comparison, a single-pathway (FISP) and a dual-pathway gradient-echo sequence were also used, with 5 repeats for noise evaluation (error bars in Fig. 2). All methods gave similar temperature values near focus (Fig. 2), and a non-heated location was used for noise evaluation. Temperature noise was measured at 0.085°C for FISP-only EPI and 0.075°C when including the PSIF, for a 13% improvement. 2) Contrast. Figure 3 shows how a weighted difference between FISP and PSIF images can provide images where blood vessels are conspicuous, potentially useful for motion tracking. 3) TE corrections. Further heating experiments were performed with the proposed method while modifying shim parameters. Following a high-order shim, PSIF and FISP heating curves were in good agreement (Fig. 4b). But prior to the shim, considerable discrepancy was present (Fig. 4c). Solving the equation above gave ΔTE=1.38ms, allowing new temperature curves to be computed, and Fig. 4d is the corrected version of Fig. 4c. The inter-echo spacing in our EPI train was 0.696ms, so that $\Delta TE = 1.38/0.696 = 1.98 \approx 2$ echoes. Using only the usual FISP signal, temperature would have been overestimated in this case (green curve in Fig. 4c).

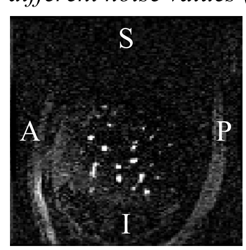

Fig. 3: *Image showing mostly blood vessels in the liver, calculated based on FISP – a×PSIF, a = 1.4 here.*

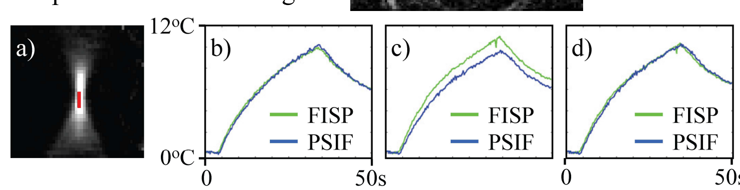

Fig. 4: *a) Region around focus, 9x9cm. An ROI with 4 hottest voxels, shown in red, was used to generate plots. b,c) After and before high-order shimming, respectively. d) Corrected version of (c),* Δ*TE=1.3ms.*

Conclusion: The proposed method has advantages in terms of temperature-to-noise ratio, tissue contrast and temperature accuracy.

[1] de Senneville et al. MRM 2007;57:319.
[2] Holbrook et al. MRM 2010;63:365.
[3] Madore *et al.* ISMRM 2009:441.
[4] Diakite et al. ISMRM 2010:1825.
Support from grant U41RR019703 is acknowledged.