Optimization of Dual-Pathway Unbalanced Steady-State Sequences for Robust Temperature Imaging

Lawrence P Panych[1], Renxin Chu[1], Chang-Sheng Mei[1], Guangyi Wang[1,2], W Scott Hoge[1], Matthew Toews[1], and Bruno Madore[1]

[1]*Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA, United States,* [2]*Department of Radiology, Guangdong General Hospital, Guangdong Academy of Medical Sciences, Guangzhou, Guangdong, China*

Target Audience: MR physicists and engineers involved in MR thermometry applications.

Purpose: Dual-pathway steady-state FISP-PSIF sequences have been proposed[1] for use in monitoring temperature during thermal therapies such as focused ultrasound liver ablation. A number of advantages of this dual-contrast sequence have been claimed including improved temperature-to-noise ratio (TNR) over the standard single-echo T2* weighted gradient-echo sequence. The purpose of this study was to optimize the dual-pathway sequence by simulating results over a range of parameters, compare the TNR with an alternative dual-echo FISP-FISP sequence and validate results of simulations through *in vivo* abdominal imaging.

Methods: *In vivo* abdominal images were obtained on a 3T scanner using a multi-shot EPI, dual-pathway sequence with sampling of a spin-echo like PSIF early in the TR interval, and a gradient-echo FISP late in the TR interval. This sampling strategy ensures that both PSIF and FISP images have maximal temperature sensitivity. Imaging parameters were: 128×96, 24 cm FOV, with 5 mm slice thickness. TRs of 9, 11, 14 and 17 ms were used for sequences with EPI echo-train lengths of 2, 4, 6 and 8 respectively.

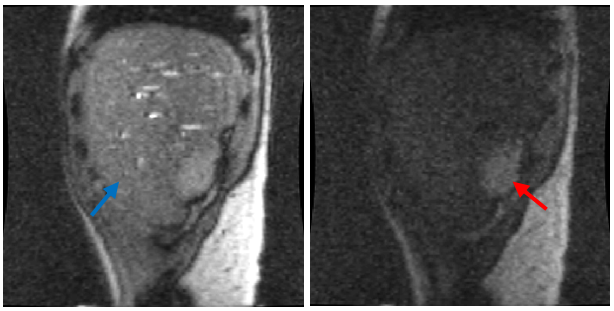

Figure 1: Example of FISP (left) and PSIF (right) images produced by the dual-pathway sequence (Sagittal, TR = 9ms, ETL=2). The red/blue arrow points to the kidney/liver, respectively.

A simulation program was created to generate dual-pathway unbalanced steady-stage images for a range of tissue T1s and T2s. For each T1-T2 combination, a variety of TRs and flip angles (FAs) were used. To simulate the effect of T2* on the signal, isochromats with different frequencies were included. Results were used to determine optimal parameters to maximize TNR for tissue T1 and T2 similar to those reported for human liver and kidney. To validate the simulation's ability to accurately predict signal levels, ROIs were selected from *in vivo* human abdominal images such as those in Fig.1. These ratios were obtained for images of several TRs and compared to simulation results.

Results: Figure 2 demonstrates the correlation between PSIF-FISP ratios calculated from selected liver and kidney ROIs in images compared to the predicted ratios from simulation. This agreement between *in vivo* imaging and simulation served as a partial validation of the simulation method used for further sequence optimization of the dual-pathway sequence for liver and kidney temperature imaging.

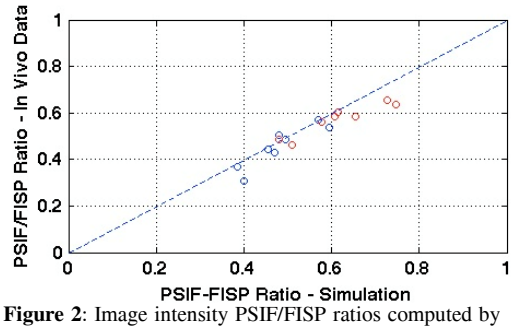

Figure 2: Image intensity PSIF/FISP ratios computed by simulation compared with ratios measured in liver (blue circles) and kidney (red) ROIs in human images.

The 2D color displays in Fig.3 represent ratios of TNR obtained when the PSIF-FISP sequence is used as compared to the TNR if the dual-echo sequence had included instead a second FISP (i.e., a FISP-FISP sequence). Ratios of greater than 1 (a PSIF gives higher TNR than using an additional FISP) are indicated by the green scale. Ratios less than 1 (a second FISP would give better TNR) are indicated by the red scale. While the simulation results show that the PSIF-FISP strategy is superior in terms of TNR for kidney imaging at almost any choice of TR and FA, in the liver the PSIF-FISP strategy is TNR superior only for TRs less than about 20ms. The contour lines represent relative PSIF-FISP signal level (as a percentage) at each TR. For the liver, the results suggest that a FA of around 20° maximizes TNR for the PSIF-FISP sequence, whereas 25° proves preferable for kidneys.

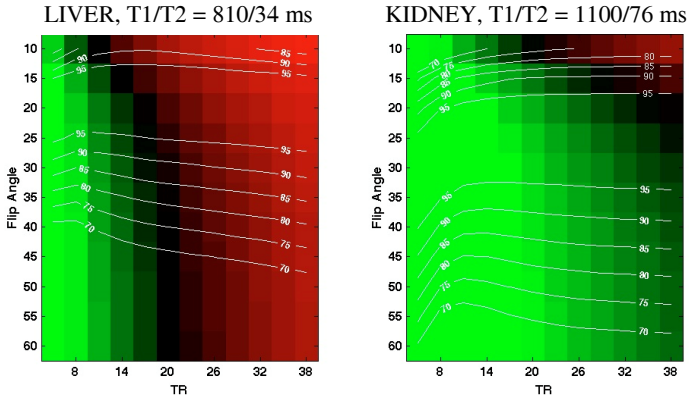

Figure 3: Ratios from simulation of TNR ratios for PSIF in dual-pathway sequence versus using extra FISP as function of TR and FA. Details in text.

Discussion and Conclusions: Dual-pathway PSIF-FISP sequences have been proposed for temperature monitoring[1]. In addition to providing temperature sensitivity, the inclusion of both gradient- and spin-echo-like contrast allows for additional possibilities beyond simple temperature mapping, e.g, for real-time detection of irreversible thermal damage. High TNR, however, is the critical metric requiring careful sequence optimization[2]. The simulation approach presented here (with partial validation from *in vivo* results) allows one to select optimal TR and FA to be used for different organs such as the liver and kidney. The simulations also clearly define organ-specific limits where the PSIF-FISP sampling strategy is TNR-superior compared to a simple dual-echo FISP-FISP sampling – e.g. at almost all TRs and FAs for kidney imaging and at 20° FA and < 20 ms TR in the liver. At a TR of 20 ms, multi-shot EPI with ETLs up to 10 are possible enabling fast abdominal thermal imaging that is fairly insensitive to respiratory motion.

References: [1] Madore et al. MRM 2011;66:658. [2] Rieke et al. MRM 2004;51:1223. Support from R01CA149342 and P41EB015898 is acknowledged.