# Dual-echo sequence for MR thermometry in moving objects

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**Introduction:** When performing MR thermometry in static objects, the choice of pulse sequence and imaging parameters is mostly dictated by temperature-to-noise (TNR) considerations. In contrast, when performing thermometry in moving objects other important factors besides TNR must also be considered. Good temporal resolution and useful contrast are required to track internal features such as blood vessels, to allow organ motion and deformation to be resolved. A thermometry dual-echo sequence introduced at last year's meeting [1] was improved here in two major ways: Its temperature sensitivity (and TNR) is increased, and greater control is introduced toward orienting its inherent velocity sensitivity. With these improvements, a claim could be made that the present dual-echo sequence is more efficient in terms of TNR than currently available approaches, making it potentially useful even in static objects. But in moving organs the advantages of the proposed sequence are even more significant, as contrast and motion-sensitivity differences between the two echoes allow blood vessels to be readily identified, for motion detection purposes.

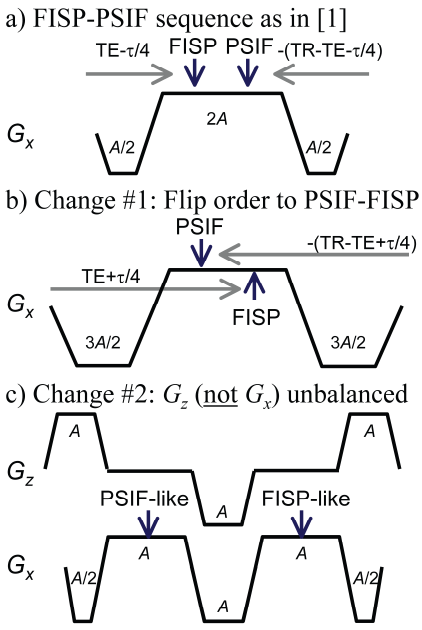

Fig. 1

**Theory:** The $G_x$ waveform of the dual-echo thermometry sequence introduced in [1] is depicted in Fig. 1a. It is similar to that of the DESS sequence from Siemens, typically used for musculoskeletal applications. Both the so-called 'FISP' and 'PSIF' echoes are sensitive to temperature, and this sensitivity is proportional to the length of the gray arrows in Fig. 1a (TE-τ/4 and TR-TE-τ/4, where τ is the readout duration). The first major change involves inverting the order of the FISP and PSIF, thus increasing the temperature sensitivity of both echoes (note that the gray arrows are longer in Fig. 1b than in Fig. 1a). This increase in temperature sensitivity is meant to translate into an increase in TNR. The second major improvement involves better control of the orientation of the velocity sensitivity. In Fig. 1b, the $G_x$ waveform is unbalanced, leading to significant velocity sensitivity along $x$, typically oriented along the S/I direction. In contrast, in Fig. 1c the $G_z$ waveform (rather than $G_x$) is unbalanced, leading to significant motion sensitivity along $z$, oriented R/L here. Because organs move mostly along S/I during free breathing, velocity sensitivity along S/I could lead to intravoxel dephasing and signal losses. In Fig. 1c this weakness is turned instead into an advantage, as velocity sensitivity along R/L facilitates the detection of blood vessels with an R/L orientation, which prove ideal for tracking the S/I and A/P motion of organs.

**Results:** The ability of the proposed approach from Fig. 1c to accurately capture temperature changes was tested in phantoms. The time frame featuring maximum heating (about 12 °C at focus) in one of these experiments is shown in Fig. 2 (T map on left, overlay on right, 128x96, 5 mm slice, 24x24 cm, TR=6.0 ms). The ability to capture blood vessels was tested in free-breathing liver imaging experiments, and one time frame from one of five slices is shown in Fig. 3 (128x96, 5 mm slice, 24x24 cm, TR=6.4 ms). Notice that blood vessels tend to appear bright in the FISP image and dark in the PSIF image, as opposed for example to fat which appears bright in both images.

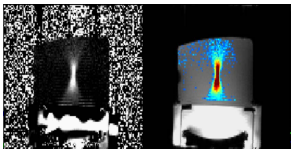
Fig. 2

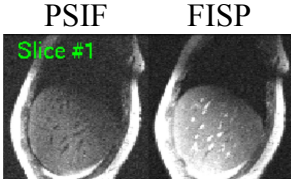

Fig. 3

**Discussion:** A large number of possible echo pathways could possibly be sampled, all with different temperature sensitivity and image contrast properties. Through simulations we verified that the FISP and the PSIF pathways offer the most TNR over expected $T_1$, $T_2$, flip angle and TR values. Typical thermometry sequences sample only the FISP pathway, either with an EPI readout or a more simple single-line readout. As the FISP magnetization has maximum temperature sensitivity for large TE values, the beginning of the TR period in such sequences is either un-utilized or ill-utilized. Exploiting the early part of the TR period to sample the PSIF magnetization makes perfect sense in terms of TNR, as the PSIF has maximum temperature sensitivity early within TR (e.g., see Fig. 1b). Furthermore, the PSIF provides valuable complementary contrast information (see Fig. 3). In the present work, single-line readouts and short TR values (6 ms) were used (Fig. 1c). Such settings lead to good quality images with minimum susceptibility-induced distortion, at a price in terms of temperature sensitivity and temporal resolution when compared to EPI readouts. Indeed, an EPI readout would lead to longer TR and TE for increased temperature sensitivity, and would give greater temporal resolution than the present single-line implementation, but at a price in image quality and distortion. In any case, regardless of the readout type (single-line, EPI or other), sampling the PSIF magnetization in the early part of TR is expected to bring significant added value over sampling only the FISP.

**Conclusion**: There is significant added value in terms of TNR and image contrast in sampling the PSIF magnetization early within TR, while still sampling the FISP magnetization as usual in later parts of the TR interval. This statement is expected to remain true regardless of the type of readout being used, whether single-line (as done here), EPI or other.

[1] Madore *et al.* ISMRM 2009, pp. 441. Discussions with Dr. McDannold and support from grant U41RR019703 are acknowledged.