B_0 DRIFT AND RESPIRATORY MOTION CORRECTION BY DUAL-ECHO SUSCEPTIBILITY CORRECTION (DESC)

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PURPOSE To propose a novel iterative reconstruction-based method named dual-echo susceptibility correction (DESC), which compensates susceptibility changes due to systematic B_0 drift and respiratory motion and calculates accurate temperature difference maps (ΔT) during thermal therapies, such as laser-induced thermal therapy, radio-frequency ablation or High Intensity Focused Ultrasound.

THEORY Proton resonance frequency shift (PRF) MR thermometry has been a popular method of choice for MR thermometry. PRF calculates temperature difference maps by subtracting pre-treatment baseline phase images from intra-treatment phase images. It relies on the principle that temperature rise (ΔT) can induce susceptibility changes (ΔB_0).[1] However, ΔB_0 contains not only $B_c(\Delta T)$, the susceptibility changes due to ΔT , but also δB, the susceptibility changes due to B_0 drift and respiratory motion. Thus, PRF is sensitive to respiratory motion and B_0 drift.[2] DESC removes δB by iteratively modeling this term from the ΔB_0 measured by Multi-Pathway EPI (MP-EPI). This sequence samples two phase images: Φ_1 (FISP) and Φ_2 (PSIF) at two echoes: TE_1 (FISP) and TE_2 (PSIF), in each TR.[3] Thus, ΔB_0 can be calculated by:[4] $\Delta B_0 = \frac{\phi_1 - \phi_2}{\gamma(TE_1 - TE_2)}$. Iterative reconstruction is performed as follows:

1) δB is estimated by a polynomial function[2]:

$$\delta B_i = \begin{pmatrix} 1 & x_0 & y_0 & \dots & y_0{}^4 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_n & y_n & \dots & y_n{}^4 \end{pmatrix} \begin{pmatrix} c_0 \\ \vdots \\ c_{15} \end{pmatrix} = X\mathrm{C_i}, \qquad [1]$$

where c_0, … c_{15} are the coefficients of the polynomial function (set as ones for the 1st iteration) and i is the current iteration. 2) 2) Calculate the intermediate B_0 shift corrected temperature difference map derived from Madore et al:[3]

$$\Delta T_i = \frac{I_1(\phi_1^{therm} - \phi_1^{base} - \gamma TE_1 \delta B_i) + I_2(\phi_2^{therm} - \phi_2^{base} - \gamma TE_2 \delta B_i)}{\gamma \alpha B_0 (TE_1 I_1 + TE_2 I_2)} \qquad [2]$$

, where $\phi_{1,2}^{base}$ and $\phi_{1,2}^{therm}$ are sampled at pre-treatment and intra-treatment respectively; I_1 and I_2 are magnitude images from FISP and PSIF.

3) Solve c at iteration i (i.e. C_i) by the least square solution of:

$$X\mathrm{C}_i = \Delta B_0 - B_c(\Delta T_i), \qquad [3]$$

where $B_c(\Delta T_i) = B_0 \alpha \Delta T_i$, where $\alpha = 0.001 \frac{ppm}{°C}$ is the PRF change coefficient for aqueous tissue. Once $|C_i - C_{i-1}| < 0.001$, the algorithm stops, and an accurate ΔT is reconstructed.

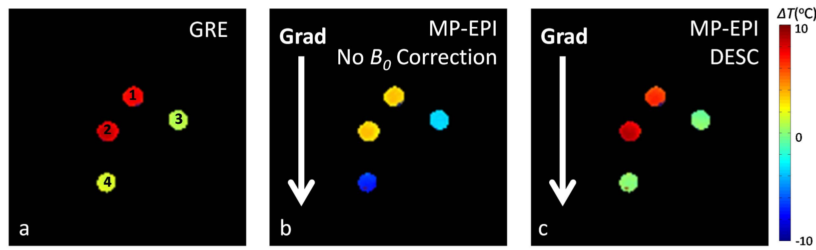

Figure 1: The ΔT maps (°C) from the phantom experiment. ΔT map acquired using (a) GRE (reference). (b) MP-EPI and no B_0 correction and (c) proposed DESC method. The direction of the linear gradient is shown by the white arrows.

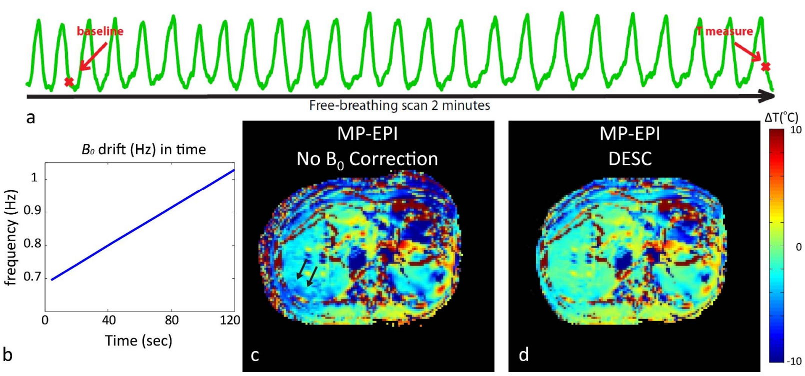

Figure 2: Results of the normal subject experiment. (a) The curve of the respiratory motions during the entire two minutes scan. The time points of the images acquired at the baseline and the assumed thermal therapy are marked by the red crosses. (b) B_0 drift (Hz) as a function of time. This was extracted from the smooth modeling function. Both (c) and (d) are from the same raw data acquired by MP-EPI. They are reconstructed without and with B_0 correction respectively.

METHODS All experiments were performed on a 3T scanner (Magnetom Trio, A TIM system, Siemens, Germany). *Phantom* To simulate the temperature rise due to thermal therapy, tube 1 and 2 were stored in a refrigerator (1°C) overnight before the experiment and were imaged in the morning. As a reference, tube 3 and 4 were kept at room temperature (19°C). A GRE sequence was used as a reference to detect the temperature changes (ΔT). ROIs were placed within each tube to measure the ΔT (mean ± standard deviation). To mimic the B_0-related changes, a linear gradient of 1mT/m in the readout direction was turned on during the acquisition of intra-treatment images by MP-EPI. *Normal Human Subjects* To evaluate the respiratory motion correction by DESC, normal human subject experiments were performed ($N=3$). During the scans, curves of respiratory motion were synchronized and recorded by a respiratory bellow placed on the chest of the subjects. B_0 drift was extracted as the coefficient c_0 of the smooth modeling function. *Imaging Protocols* In all experiments, GRE was sampled as: TE=10 ms, TR=40 ms, flip angle=15°; MP-EPI used: TE_1=11 ms, TE_2=14 ms, TR=18 ms, EPI factor=5, flip angle=30°. The other parameters were: FOV=300 x 300 mm^2, image matrix=128x128, slice thickness 5 mm. To evaluate DESC, ΔT from MP-EPI without DESC was calculated by using equation [2] from Madore et al.[3]

RESULTS and DICSUSSION Figure 1 depicts the ΔT maps (°C) of all tubes (1-4) obtained using GRE (Fig 1a), MP-EPI with no B_0 correction (Fig 1b) and MP-EPI with DESC (Fig 1c). Their ΔTs are: Tube 1: 7.5±0.2 (GRE), 4.2±0.3 (MP-EPI), 7.1±0.2 (MP-EPI with DESC); Tube 2: 8.4±0.3 (GRE), 3.8±0.3 (MP-EPI), 8.4±0.3 (MP-EPI with DESC); Tube 3: 0.9±0.1 (GRE), -3.5±0.2 (MP-EPI), 1.2±0.2 (MP-EPI with DESC); Tube 4: 1.5±0.1 (GRE), -8.1±0.3 (MP-EPI), 1.6±0.2 (MP-EPI with DESC). Thus it can be observed that the proposed DESC method reduces the B_0-related changes induced by linear gradient. Figure 2 show that the proposed DESC method can reduce the B_0 drift and the respiratory motion of a normal human subject. Significant susceptibility changes are observed in Fig 2c, since the baseline and the intra-treatment phase images were sampled at 2-minute intervals (Fig. 2a) and different respiration phase. In Fig 2b, 0.3 Hz B_0 drift over the two-minute scan is shown, and a 0.003 Hz/s linear change is observed due to respiration. Fig 2c shows pronounced temperature inaccuracies due to B_0 drift and respiratory motion (arrows). By using the proposed DESC method, those inaccuracies are minimized as seen in Fig 2d.

CONCLUSION The proposed DESC method can minimize the B_0 changes due to systematic B_0 drift and respiratory motion and calculate accurate temperature difference (ΔT) maps, thereby overcoming the limitation of baseline subtraction method.

REFERENCES 1. Rieke et al JMRI 2008; 2. Madore et al MRM 2011; 3. Haacke et al John Wiley 1999; 4. Grissom et al Med Phy 2010.