Efficient B0-inhomogeneity insensitive TQF ^{23}Na Imaging.

L. Fleysher[1], N. Oesingmann[2], and M. Inglese[3]
[1]Department of Radiology, NYU School of Medicine, New York, New York, United States, [2]Siemens Medical Solutions USA, Inc., United States, [3]Departments of Radiology and Neurology, NYU School of Medicine, New York, New York, United States

Introduction

It is desirable to differentiate the signal due to free sodium ions (*e.g.* extra-cellular sodium) from that due to sodium ions restricted in their mobility (*e.g.* intra-cellular) *in-vivo*. One such method of discrimination is triple-qunatum filtering (see for example, [1,2,3]). It is well known [2,3] that TQF signal is severely damaged by possible B_0-inhomogeneities. The method of Wimperis *et. al.* [2] solved this problem by dephasing two out of the four contributing pathways using a gradient pulse, while the technique of Tanase and Boada [3] extracted all four contributing signals and corrected for B_0 in post processing. Unfortunately, these approaches lead to loss of SNR efficiency. Here, we propose a new method which combines the advantages of the two techniques. In our method, the signal is split into two pairs of two coherence transfer pathways and the corresponding B_0 correction is applied to each pair separately. This increases the TQF SNR efficiency by a factor of $\sqrt{2}$ compared to the references [2,3]. In addition, if the signal to noise ratio is relatively high (SNR>5), the method can produce accurate B_0-corrected TQF images even without additional B_0-map information. We present the theory and a phantom validation of the method.

Theory

Consider the TQF sequence [3,4] which consists of three excitation pulses of the same flip angle θ and corresponding phases ϕ_{123} and separated by delays $\tau_{1,2}$ (see Figure 1) followed by a readout. The received signal is (see for example [3,5]):

$$S_\Omega(\phi_1,\phi_2,\phi_3,t) = \sum_{p_1=\ 1}^{1}\sum_{p_2=\ 3}^{3} e^{-i(p_1\phi_1+(p_2-p_1)\phi_2-(1+p_2)\phi_3)}B_{p_1p_2} \tag{1}$$

$$B_{p_1p_2} = e^{-i(p_1\tau_1+p_2\tau_2)\Omega}e^{i\Omega t}A_{p_1p_2} \tag{2}$$

where Ω is the B_0-field inhomogeneity and A_{p1p2} is the amplitude of the specified coherence pathway. The TQF signal is:

$$S^{TQ} = A_{+1-3} - A_{-1-3} - A_{-1+3} + A_{+1+3}$$

$$\approx e^{-i\Omega t}\textstyle\sum_{p_1=\pm1} p_1\left[B_{p_1-3}+B_{p_1+3}\right]e^{+ip_1\Omega\tau_1} \tag{3}$$

Consequently, the acquisition of B_0-corrected TQF data would consist of a B_0-mapping acquisition followed by a 12-step phase cycle: 1. Acquire signals $S_{1;k}$ with $\phi_{1;k} = 2\pi k/6$, $\phi_{2;k} = 2\pi k/6$, $\phi_{3;k} = 0$ for k=0,1, …,5; 2. Acquire signals $S_{2;k}$ with $\phi_{1;k} = \pi/2 + 2\pi k/6$, $\phi_{2;k} = 2\pi k/6$, $\phi_{3;k} = 0$ for k=0,1,…,5. The B_0-corrected TQF signal can be restored according to equation (3) taking into account (4):

$$B_{p_1+3} + B_{p_1-3} = \frac{1}{2}\sum_{k=0}^{5}(-1)^{k+1}\left(S_{1;k} + ip_1S_{2;k}\right) \tag{4}$$

Results and Conclusions.

To validate the method, phantom experiments were performed on a 3T whole-body MAGNETOM Trio, A Tim System (Siemens AG, Germany) with a dual-tuned TX/RX ^{1}H/^{23}Na head coil (Stark Contrast, Germany) and a modified GRE sequence (see Figures 1-3). The RF excitation train was comprised of three non-selective pulses of 500 µs duration each. Acquisition parameters for the TQF imaging were 240x240x240 mm^3 FOV with 16x16x16 encoding matrix; TR=165ms, TE=6.6ms, FA=90^0 and τ_1=5.5ms τ_2=150µs. The images were acquired both with a 24-step cycle [3] and with the 12-step phase cycle as described here. SNR efficiency improvement between the 12-step and the 24-step methods is 1.47+/-0.08 which is in an agreement with theoretically predicted value of $\sqrt{2} \approx 1.41$ (see Figure 3).

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References. 1. Jaccard, et. al. J Chem Phys 85:6282, 1986. **2.** Wimperis, et. al. J Magn Reson 98:628, 1992. **3.** Tanase, et. al. et. al. J Magn Reson 174:270, 2005. **4.** Hancu, et. al. Magn Reson Med 42:1146, 1999. **5.** Keeler, Understanding NMR Spectroscopy, Wiley&Sons, 2005.

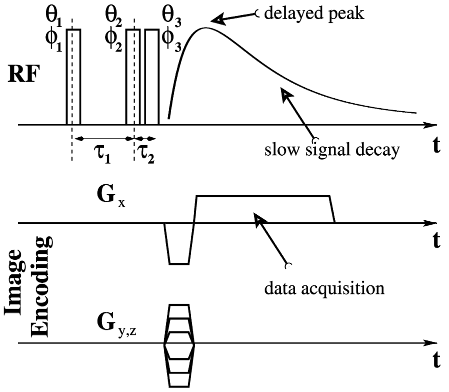

Figure 1: The schematic diagram of the TQF excitation block superposed with signal evolution and imaging readout.

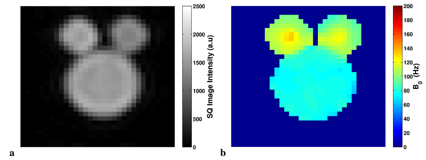

Figure 2: (a) A single-quantum sodium image of the phantom setup. Small bottles contain 4% agar gel with sodium, while large bottle contains saline. (b) B_0-map of the same slice. The field gradients cause minor intra-voxel dephasing on single-quantum images, but cause major signal dropout on the triple-quantum images (see Figure 3).

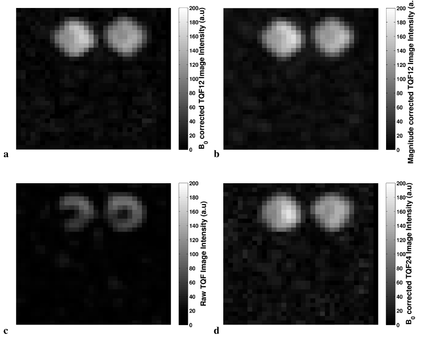

Figure 3: TQF image produced by the 12-step cycle after B_0 correction (a) and after magnitude B_0 correction (b). B_0-uncorrected TQF image (c) reveals signal dropouts in the areas of magnetic field offsets. For comparison, the TQF image produced with a 24-step cycle is presented in panel (d). SNR efficiency improvement between the 12-step and the 24-step methods is 1.47+/-0.08 which is in an agreement with theoretically predicted value of $\sqrt{2} \approx 1.41$.