Variable Bandwidth Turbo Spin-Echo Dixon Imaging

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Purpose

Dixon imaging involves chemical shift encoding in the acquisition to allow a separation of water and fat signal in the reconstruction. In turbo spin-echo (TSE) Dixon imaging, the chemical shift encoding is commonly realized by repeated acquisitions with different shifts of the readout gradient and the sampling window, which permit collecting several echoes at different time shifts with respect to the spin-echo[1]. These so-called echo shifts increase the minimum spacing between successive refocusing pulses in the TSE sequence and thus affect the scan time and signal-to-noise ratio (SNR). However, analyses of the SNR in TSE Dixon imaging have considered the direct influence of the choice of these echo shifts only, i.e. the noise propagation in the reconstruction[1,2]. In this work, the indirect influence via the TSE sequence is taken into account as well, and an individual optimization of the readout gradient, the bandwidth, and the sampling window for each acquisition is suggested to enhance the SNR.

Methods

For a meaningful comparison of different choices of the echo shifts ΔTE with respect to the resulting SNR in in-phase (IP) and water-only images, the spacing between successive refocusing pulses or spin echoes ΔT in the TSE sequence needs to be fixed. As illustrated in Fig. 1, stronger readout gradients, higher bandwidths, and shorter sampling windows must then be employed to accommodate the echo shifts, leading to a lower SNR. If this influence is taken into account, the established relation between the effective number of signal averages (NSA) and the echo shifts changes[1-3]. For dual-echo Dixon imaging with one IP acquisition, i.e. one acquisition without echo shift, and a nominal sampling window of 4 ms, this is shown in Fig. 2. The maximum NSA is 50% lower and is already reached for ΔTE = 0.9 ms at 3 T, which corresponds to a 140° dephasing between water and fat signal. This presupposes that in all acquisitions the same readout gradient strength, bandwidth, and sampling window length are used, which are governed by the highest absolute ΔTE. This ensures an identical fat shift in all acquisitions and thus allows substantial simplifications in the reconstruction. However, an individual optimization of both parameters for each acquisition permits enhancing the SNR. For dual-echo Dixon imaging with one IP acquisition, the NSA can be shown to increase by $2b^2/(1+b^2)$, where b is the ratio of the SNR in the source images produced from the IP and the partially-opposed-phase (POP) acquisition, i.e. the other acquisition with echo shift, respectively. The maximum NSA is then 31% higher and is reached for ΔTE = 1.0 ms at 3 T in the example in Fig. 2.

The benefit of the suggested individual optimization was evaluated in head and neck imaging on volunteers on a 3 T Ingenia scanner (Philips Healthcare, Best, The Netherlands). A Dixon method that takes the variable fat shift into account, similar to a previously described one, was applied for the separation[4].

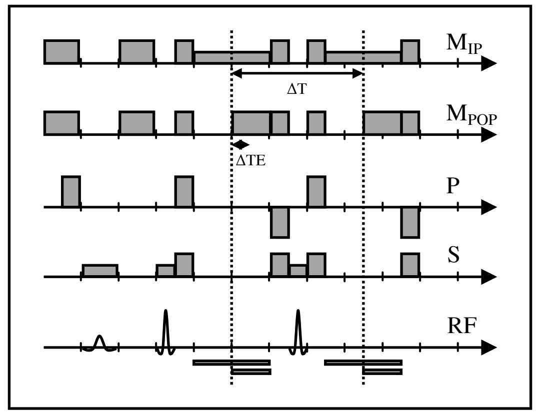

Fig. 1. Schematic sequence diagram of turbo spin-echo acquisitions optimized for SNR, without (IP) and with (POP) echo shift (ΔTE). The acquisitions share the same spin-echo spacing (ΔT), but differ in the readout gradient (M) and the sampling window (RF).

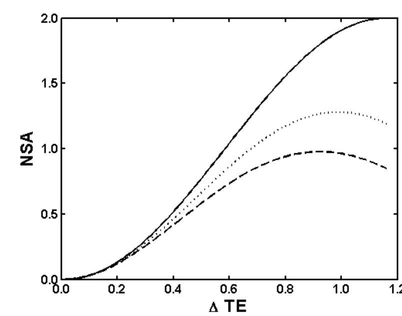

Fig. 2. Effective number of signal averages (NSA) in dual-echo Dixon imaging with one in-phase acquisition as function of the echo shift (ΔTE) [ms] at 3 T. Shown are the established relation (solid), and the relations including the shortening of the sampling window in both acquisitions (dashed) and in the partially-opposed-phase acquisition only (dotted).

Results

In the selected result shown in Fig. 3, the two source images were acquired with the same ΔT of 7.5 ms. However, the SNR in the IP source image is 42% higher than in the POP source image, for which a ΔTE of 1.0 ms was chosen. The SNR in the resulting water and fat images is increased by about 15% through the higher SNR in the IP source image.

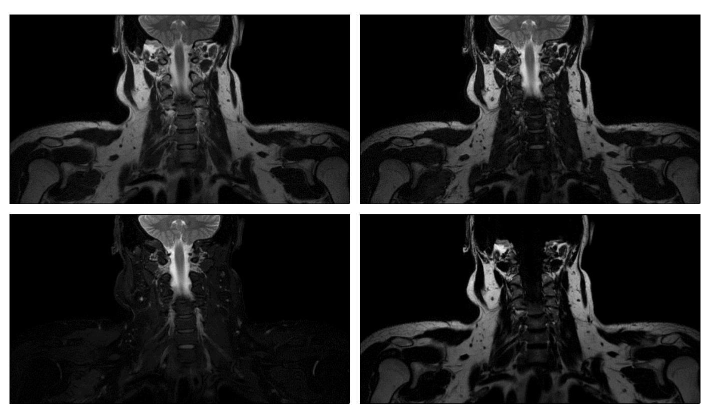

Fig. 3. Source images acquired without (top left) and with (top right) echo shift, differing in SNR by 42%, and water (bottom left) and fat (bottom right) images produced from these source images.

Discussion

While complicating the separation, the use of weaker readout gradients, lower bandwidths, and longer sampling windows for the acquisitions with lower absolute echo shifts allows improving the SNR in TSE Dixon imaging without prolonging the scan time. The increase in SNR in the acquired IP images even exceeds the increase in SNR in the reconstructed water-only images and may be exploited to offset the otherwise lower SNR in the acquired or synthesized IP images. The additional benefit of more symmetrical echo shifts currently lacks an analytical description and remains to be explored[3].

References

1. Reeder SB, et al. Magn Reson Med 2005; 54:636-644. 2. Xiang QS. Magn Reson Med 2006; 56:572-584. 3. Eggers H, et al. Magn Reson Med 2011; 65: 96-107. 4. Lu W, et al. Magn Reson Med 2008; 60:198-209.