Comparison of Biexponentially Weighted and Double-Echo Sodium Imaging

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Purpose

A weighting towards intracellular sodium is desirable to detect small changes in the sodium ion homeostasis. It is assumed that this image contrast can provide an early detection mechanism of pathological conditions in tissue that involve a breakdown of the concentration gradient of sodium ions over the cell membrane [1]. Two pulse biexponentially weighted sodium imaging has been proposed to provide the desired contrast with good image quality in short acquisition times [2]. The purpose of this work was the evaluation of benefits of biexponentially weighted sodium imaging compared to a difference image generated from a conventional double-echo sequence.

Methods

Both pulse sequences were implemented on a 7-Tesla whole-body MR system (Magnetom 7 T, Siemens, Erlangen, Germany). A double-resonant ($^1H/^{23}Na$) birdcage coil (Rapid Biomed GmbH, Würzburg, Germany) was used for the measurements. Sequence diagrams are shown in Fig. 1. Two images (*I*1 and *I*2) are acquired during the two density adapted 3D radial readout gradients [3]. The images are weighted to account for T_2^* relaxation of the cerebrospinal fluid (CSF) and subtracted to generate a the difference image (*DI*):

$$DI = I1 - \exp((-TE_1+\tau+TE_2)/T_2^*) * I2$$

To compare both methods, simulated SNR curves have been calculated and phantom and in vivo experiments have been performed.

The sequence parameters of Fig. 3 are: TE_1 = 0.55 ms, $TE_2 = \tau$ = 13 ms, TR = 150 ms, T_{RO} = 10 ms, $\Delta x^3 = (5\ mm)^3$, projections = 2000, averages = 2, T_A = 10:00 min.

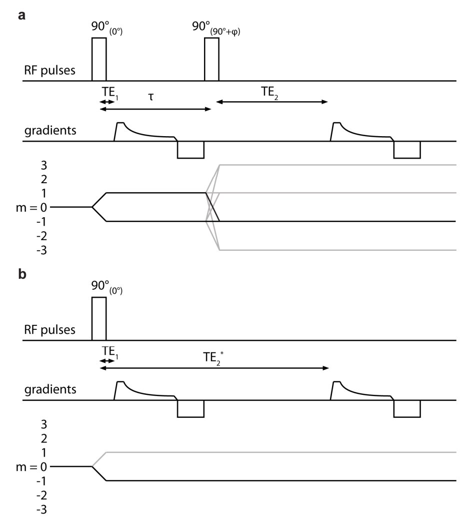

Fig.1: Sequence diagram for biexponentially weighted (a) and double-echo imaging (b)

Results & Discussion

Theoretical SNR curves as a function of correlation time are shown in Fig. 2 (normalized to SNR of a spin-density weighted image). The curve of the biexponentially weighted sequence (red) shows less variation over a wide range of correlation times compared to the curve of the double-echo sequence (yellow). An almost homogeneous signal for different correlation times is desirable as in vivo correlation times are not known. Thus, less dependence on correlation time leads to the ability to quantify the resulting signal intensity in in vivo studies.

The difference curve of both sequences is shown in blue. The shape is very similar to the course of a triple quantum filtered sequence (green). The image generated from the double-echo sequence provides a relaxation weighting, which leads to a similar contrast as biexponentially weighted imaging. However, in biexponentially weighted imaging, triple-quantum and possibly double-quantum coherences are excited after the second RF pulse and thus are lost for detection. Hence, the second acquired image yields less signal for tissue with biexponential relaxation behavior. Thus, the difference image generated from this sequence has a higher signal in these tissues compared to the difference image generated from the double-echo sequence.

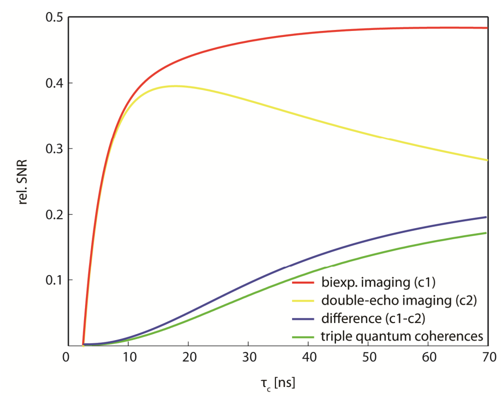

Fig.2: Theoretical SNR of the different sequences. The difference in relative SNR of biexp. weighted and double-echo imaging (blue) is close to the theoretical SNR of triple quantum filtered imaging (green).

The sequences are compared in vivo (Fig. 3). Both are capable of suppressing signal originating from CSF. In accordance to theory the biexponentially weighted sequence yields more than 14 % higher SNR (28 vs. 32). The double-echo images also show more sensitivity to field inhomogeneities (cf. red arrows). This can be explained with the coherence transfer pathway diagram of the biexponentially weighted sequence (Fig.1a). Half of the signal is refocused at the time of signal acquisition.

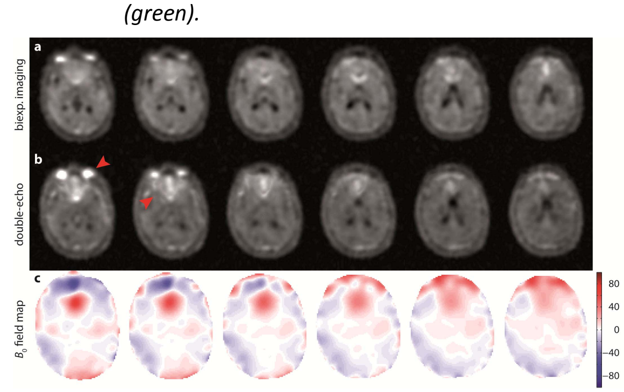

Fig.3: In vivo images (healthy volunteer, male, 30 years) acquired with both sequences. B_0 map shows areas which are prone to high off-resonance .

Conclusion

It was shown that the biexponentially weighted sequence is more suitable for future approaches for quantifying the intracellular sodium content. Also, biexponentially weighted imaging leads to higher SNR and less B_0 sensitivity.

References [1] Boada et al., Proc. of the 26th ann. int. conf. of the IEEE EMBS (2004): 5238-5241, [2] Benkhedah et al., In Proc. ISMRM (2013): 1992, [3] Nagel et al., Magn Reson Med (2009) 62: 1565-1573

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