Optimized Acquisition of Susceptibility Weighted Imaging (SWI) at 7T

A. Deistung[1], A. Rauscher[2], J. Sedlacik[1], and J. R. Reichenbach[1]

[1]Medical Physics Group, Institute of Diagnostic and Interventional Radiology, Hospital of the Friedrich Schiller-University, Jena, Thuringia, Germany, [2]UBC MRI Research Centre, Vancouver, BC, Canada

Introduction

Susceptibility weighted imaging (SWI) allows to assess the venous architecture of the brain in high spatial detail [1,2]. The method is based on a first-order velocity compensated 3D gradient echo sequence and uses low flip angles of about 10 to 20 degrees which lead to specific absorption rates (SAR) well below the limits. Imaging veins with smaller blood volume fractions is possible at 7T compared to 1.5T due to increased intra- and extravascular susceptibility gradients and shorter T_2^* relaxation of venous blood (below 7ms). The aim of this study was to optimize SWI data acquisition for 7T with respect to venous vessel visualization.

Material and Methods

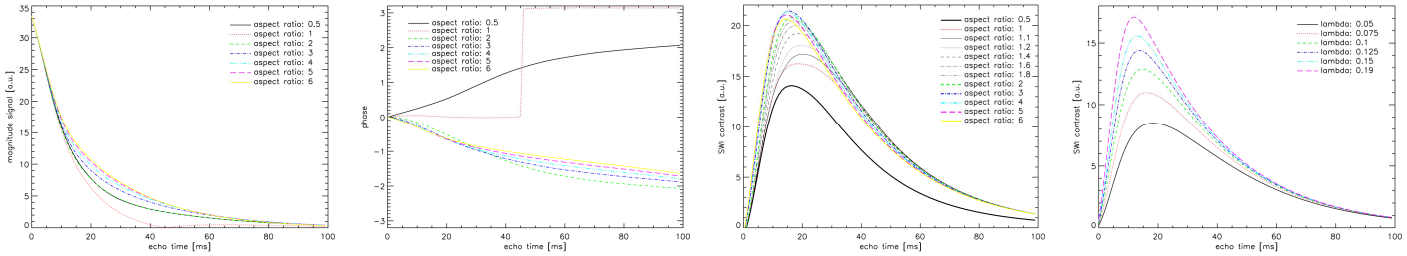
The complex signal decay for a voxel traversed by a single cylindrical venous vessel (oriented perpendicular to $\mathbf{B_0}$ [θ = 90°]) was simulated [3] for an axial SWI acquisition based on blood's (T_1 = 2587 ms [4], T_2 = 7 ms [5]) and white matter's (WM, T_1 = 1220 ms [4], T_2^* = 26.8 ms [6]) relaxation times. The magnitude and phase of the vessel voxel were then plotted as a function of echo time (Fig. 1(a) and 1(b)). Furthermore, the SWI contrast between the vessel voxel and homogeneous tissue (WM) was calculated by subtracting the SWI signal of the vessel voxel, which was obtained by fourfold multiplication of the phase mask with its corresponding magnitude [2], from the signal of the WM voxel (given by the T_2^*-signal decay). The simulations were carried out for different voxel aspect ratios (slice thickness : inplane resolution) and blood volume fractions (λ). In addition, data of a single volunteer were acquired at echo times of 8.6ms, 11ms, 14ms, 17ms, and 20ms with the SWI sequence (TR/FA = 25 ms/12°, matrix = 512 × 384 × 40, partial Fourier 75% in both phase encoding directions) by using a head array with 8 independent transmit/receive channels (RAPID Biomedical, Würzburg, Germany) on a Magnetom 7T MR-scanner (Siemens Medical Solutions, Erlangen, Germany). To achieve the short echo time of 8.6 ms all data were measured with asymmetric echo readout of 20%. Susceptibility weighted images were reconstructed using the standard SWI method [2] and coregistered using Flirt (FSL, FMRIB, Oxford, UK).

Results

The simulation of the imaging parameters for 7T (Fig. 1) yielded optimum SWI contrast between veins and surrounding white matter for an echo time of about 14ms (Fig. 1 (c)). The contrast was very similar for all voxel aspect ratios equal or greater than 2 (Fig. 1 (c)), but was very sensitive to changes in TE for echo times lower than the optimal TE. Being less sensitive for echo times higher than the optimal TE, the loss of contrast at long echo times can be attributed to the T_2^* decay of the surrounding tissue due to the disappearance of the intravascular signal. The simulations of different partial volume fractions revealed that the optimum echo time depends weakly on the blood volume fraction (Fig. 1(d)). If the venous vessel is surrounded by gray instead of white matter, the SWI contrast is superior due to gray matter's slower T_2^* relaxation (T_2^*=33.2ms [6]). The venograms acquired at various echo times (Fig. 2) confirm the results of the simulation (compare Fig 1). Small venous vessels in white matter tissue (highlighted by white boxes) are excellently delineated using echo times in the range of 11–14 ms. Shorter echo times (8.6 ms) lead to inferior visualization of these small vessels because of smaller phase offsets induced by the veins. The venous contrast is also decreased with longer echo times (17–20 ms) due to reduced signal caused by T_2^* relaxation. However, the larger phase offsets improve the visibility of paramagnetic structures, such as the basal ganglia, whereas the interpretation of regions near large field inhomogeneities, e.g., in the frontal brain, is limited.

Discussion

The fast transverse relaxation of venous blood of 7ms at 7T results in a very rapid signal loss and, therefore, negligible intravascular phase shifts (see aspect ratio 1 in Fig 1(b)). For instance, only 13% of blood's original signal is left at TE = 14ms. Since for veins parallel to $\mathbf{B_0}$ the venous contrast only arises from the intravascular signal contribution, the short T_2^* of blood at 7T may reduce the visibility of these vessels in magnitude and susceptibility weighted images, especially for low blood volume fractions. For venous vessels oriented perpendicular to $\mathbf{B_0}$ the visibility mainly comes from intra-voxel spin dephasing due to extra-vascular field inhomogeneities. In conclusion, SWI data acquisition is optimized by using a transverse slice orientation, echo times of about 14 ms and a voxel aspect ratio larger than 2.

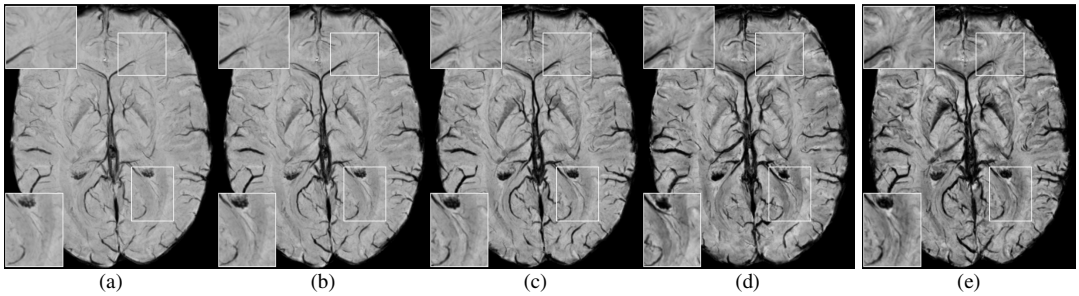


(a) (b) (c) (d)

Figure 1: *Numerical simulations of magnitude, phase and SWI contrast for different aspect ratios (slice thickness : inplane resolution) of a voxel containing white matter and a vein with a blood volume fraction λ of 10% (θ=90°, blood's hematocrit: 0.45 and oxygen saturation: 0.55, B_0 = 7T). The (a) magnitude and (b) phase are plotted as a function of echo time. The SWI contrast (i.e., the combination of magnitude and phase mask) between the venous voxel ((a), (b)) to another white matter voxel is plotted in (c). (d) Simulation of the SWI contrast towards white matter in dependence of the blood volume fraction λ for the aspect ratio 4. The optimum TE increases weakly with decreasing volume fraction.*

Literature

[1] Reichenbach JR et al. NMR Biomed 2001;14: 453–467
[2] Haacke E et al. Magn Reson Med 2004;52:612–618
[3] Sedlacik J et al. Magn Reson Med. 2007 Nov ; 58(5): 1035-44
[4] Rooney WD et al. Magn Reson Med 2007;57:308–318
[5] Yacoub E et al. Magn Reson Med 2001;45:588–594
[6] Peters AM et al. Magn Reson Imaging 2007;25(6): 748-53



(a) (b) (c) (d) (e)

Figure 2: *Minimum intensity projection of susceptibility weighted images over 10mm of a volunteer acquired with (a) TE=8.6ms, (b) TE= 11ms, (c) TE= 14ms, (d) TE= 17ms and (e) TE= 20ms at 7T. The selected sections demonstrate superb delineation of small vessels close to the V. septi pellucidi and the optic radiation for echo times ranging from 11 to 14ms.*