ToF-SWI: A Dual-Echo Sequence for simultaneous Time-of-Flight angiography and Susceptibility Weighted Imaging

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Introduction

Imaging the arterial and venous vascular architecture of the brain simultaneously with high spatial resolution is of high diagnostic and therapeutic interest. Recently, a dual-echo gradient echo sequence was introduced that combines time-of-flight (ToF) [1] and a second echo with flow compensation in readout-direction only. The first echo (ToF echo) employs the inflow of unsaturated spins into the acquisition volume for arterial imaging [2]. The second echo utilizes the blood oxygenation level dependency effect (BOLD) [3] to image venous vessels. We present a 3D dual-echo gradient-echo MR-sequence with full 3D first order flow compensation of the second echo (ToF-SWI). To optimize ToF-SWI data acquisition we investigated the influence of flip angle (FA), parallel imaging acceleration factor, as well as the issue whether full flow compensation of the second echo is required.

Material and Methods

The ToF-SWI sequence was implemented on a 1.5T (Avanto, Siemens Medical Solutions, Erlangen, Germany) and a 3T (Tim Trio, Siemens Medical Solutions) MR-scanner using the vendor specific development environment IDEA (version VB15, Siemens Medical Solutions). Firstly, the influence of flowing spins on the second echo of the sequence was assessed by using flow phantom (a pipe system immersed in an aqueous solution) and volunteer measurements at 1.5T. The following user-selectable options were integrated into the ToF-SWI sequence for the second echo: no flow compensation, partial flow compensation in readout direction only and full 3D flow compensation. Region of interest (ROI) based analysis of phase values in veins, white (WM) and grey matter (GM) was performed. Subsequently, arterial and venous contrasts were examined in volunteers as a function of flip angle (FA = 15°, 20°, 25° and a TONE pulse with 20° and ratio 2:1) and parallel imaging acceleration factor (R=2-4) at 3T using the following parameters: $TE_1/TE_2/TR$ = 3.42 ms/25 ms/42 ms, BW_1=271Hz/px, BW_2=76Hz/px, two slabs each with a matrix of 512×384×44 and a slab overlapping factor of -22.73%. ToF-SWI data were also compared with corresponding additionally acquired single-echo ToF and single-echo SWI data at 3T. Phase wraps were removed by homodyne filtering [4]. Susceptibility weighted images were computed by combining magnitude and unwrapped phase images of the second echo according to the standard SWI method (i.e., fourfold multiplication of the phase mask with the corresponding magnitude) [5,6].

Results

Exemplary arteriograms and venograms obtained from the ToF-SWI data are shown in Figure 1a and 1b. The effects of different flow compensation (FC) conditions of the second echo are summarized in Figures 1d-f. The fully flow compensated echo readout mapped arteries as hyperintense structures (Fig. 1f). With the other conditions, signal voids in the middle cerebral arteries resulted in hypointense vessel representations (Fig. 1d and 1e). With partial flow compensation in readout direction only the arterial signal was also spatially displaced and blurred (Fig 1e). The ROI-based analysis (Fig 1g) revealed that the mean phase values were slightly decreased in venous vessels and showed larger standard deviations if flow compensation was not applied in all three spatial directions. The mean phase in GM and WM, however, was not significantly different across the different flow compensation conditions. The TONE pulse was found to depict arteries best while venous contrast was preserved. With increasing acceleration factors R, noise, blurring and ghosting artefacts increased, particularly in the venograms. A compromise between scan time and vessel contrast for arteries and veins was found with R=3, which was considered to be the highest acceptable acceleration factor with respect to image quality for the 12-channel head matrix coil used at 3T. Comparing ToF-SWI with single-echo ToF demonstrated arteries with similar quality and delineated all major arteries equally well. However, venous delineation was degraded due to lower SNR associated with the thinner slabs compared to single-echo SWI acquisition.

Discussion

The presented dual-echo ToF-SWI approach allows simultaneous acquisition of time-of-flight and susceptibility weighted imaging data. However, there is a trade-off between background signal suppression in ToF images and preservation of sufficiently high SNR in the SWI echo. For instance, acquisition with multiple overlapping slabs (MOTSA) improves arterial delineation in ToF-MRA due to reduced flow saturation [7], whereas compared to a single slab acquisition the SNR is reduced by a factor of $\mathrm{sqrt}(n_{slabs})^{-1}$. The 3D flow compensation of the second echo results in intrinsically co-registered arteries and veins without spatial mis-registration artifacts due to oblique flow. Full flow compensation also minimizes signal loss in arteries. Thus, potential mistaking of arteries as veins in the SWI echo is reduced. Full 3D flow compensation ensures the possibility to extract quantitative phase values of vessels resulting only from susceptibility differences to the surrounding tissue (without phase offsets due to blood flow). The potential of this sequence for neurological applications in clinical routine has to be investigated in future studies.

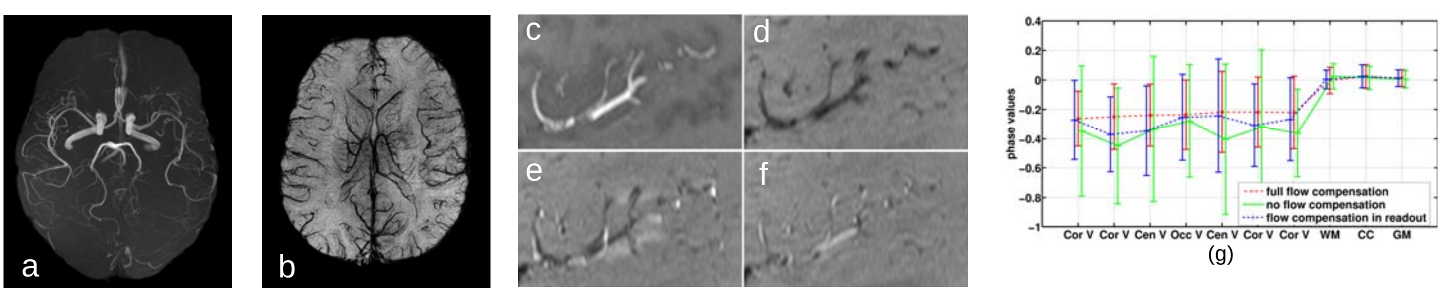

Figure 1: *Arteriogram (maximum intensity projection (MIP) over the whole volume of the first echo) (a) and venogram (minimum intensity projection (mIP) over 13.2 mm of susceptibility weighted images of the second echo) (b) of a ToF-SWI acquisition* ($TE_1/TE_2/TR/FA/B_0$ = 3.42 ms/25 ms/42 ms/20° TONE/3T, voxel size = 0.43×0.43×1.2 mm³, 3 slabs with distance factor of -20.45%). *The influence of flow compensation on vessel depiction for the second echo of a ToF-SWI experiment (*$TE_1/TE_2/TR/FA/B_0$ = 3.42 ms/40 ms/57 ms/25°/1.5T, voxel size = 0.54×0.54×1.5mm³*) at 1.5T is shown in c-g. For reference, the ToF echo is shown in (c) as a MIP over 4.5 mm. Average projections of the same volume were computed from magnitude data of the second echo acquired without flow compensation (d), with flow compensation in readout direction only (e) and 3D flow compensation (f), respectively. Means and standard deviations of phase values are plotted in (g) for seven different venous vessels (Cor V – cortical vein, Occ V – occipital vein, Cen V – central vein) and for static background tissue (WM – white matter, CC – corpus callosum, GM – gray matter).*

References

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