Sliding Time of Flight (TOF) using a tornado filter

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Introduction

Time of flight (TOF) is one of the most widely used MR angiography techniques that enhance the contrast between vessels and stationary-tissue [1, 2]. In TOF angiography, a flow-related enhancement (FRE) effect is induced by an inflow of unsaturated magnetizations (i.e. inflowing blood). In two-dimensional (2D) TOF, RF pulses with high flip angles are commonly used because they produce high contrast between vessel-to-background tissues. In spite of the high contrast, 2D TOF generates images with a low signal-to-noise ratio (SNR) and a low resolution along the slice direction compared to the three-dimensional (3D) TOF. On the other hand, the contrast between vessels and background tissues is lower in 3D TOF because RF pulses with low flip angles are used to reduce the venetian blind artifacts. In this abstract, a novel angiography method called sliding TOF is presented, which provides an angiogram with high vessel-to-background contrast, high SNR, and high slice resolution.

Methods

In TOF angiography, the signal (Sj) from blood in vessels can be determined with imaging parameters and the number of applied RF pulses as follows,

$$S_j = M_0 \sin\theta \left[f_{z,SS} + \left(\cos\theta \cdot \exp\left(-\mathrm{TR}/\mathrm{T}_1\right)\right)^{j-1}\left(1 - f_{z,SS}\right)\right] \exp\left(-\mathrm{TE}/\mathrm{T}_2^*\right), \text{ for } f_{z,SS} = \left(1-\exp\left(-\mathrm{TR}/\mathrm{T}_1\right)\right)/\left(1-\cos\theta\cdot\exp\left(-\mathrm{TR}/\mathrm{T}_1\right)\right),$$

where M_0 denotes the longitudinal magnetization at equilibrium state, j is the number of RF pulses that are applied to the spin, and θ is the flip angle of the RF pulse. According to this equation, the intensity of the signal monotonically increases as the total number of applied excitation pulses decreases. Thus, the proposed method utilizes the property that the FRE is always maximized at the blood-entering slice in an imaging slab, even if the slab thickness is large or the flip angle of the applied RF pulses is large. In the proposed method, a total imaging volume is covered with multiple 3D slabs using a subsampled stack-of-stars trajectory, where the sliding distance between adjacent slabs is equivalent to the slice thickness. The data acquisition scheme for the sliding TOF is presented in Fig. 1(a), where the acquisition order of the projection data follows the golden angle ratio technique to keep the incremental angle of the successively acquired projection data constant even for an arbitrary number of projection views. For image reconstruction, one-dimensional (1D) Fourier transform is performed first along the z direction of each 3D slab and projection data at the same z-slice position from different slabs are gathered. Since the signal intensity of blood decreases as the distance between blood vessel and blood-entering slice increases, projection data at the same z-slice position from different slabs have different blood signal intensity as shown in Fig. 1(b). In this study, a tornado filter is simply adopted for generating high contrast angiogram [3].

Results

For in vivo experiments, cerebral angiography images were obtained using the proposed sliding TOF method and the conventional multiple overlapping thin slab acquisition (MOTSA). All experiments were performed at a 3T MRI scanner (Siemens Magnetom Verio, Erlangen, Germany) using the following parameters: TR / TE = 23 ms / 5 ms, flip angle (FA) = 38°, FOV of a single slab = 250 × 250 × 20 mm^3, total longitudinal FOV = 100 mm, resolution of each slab = 0.98 × 0.98 × 1 mm^3, and a shift amount of 1 mm (slice thickness). In addition, the MOTSA with tilted optimized nonsaturating excitation (TONE) RF pulses [4] was performed for comparison, which had four overlapping slices per slab. To cover the total longitudinal FOV, five slabs were acquired for the conventional MOTSA and two different flip angles (low FA = 18° and high FA = 38°) were used to demonstrate the effect of flip angles in MOTSA. Fig. 2 shows the maximum intensity projection (MIP) of the reconstructed images from the conventional MOTSA and the proposed method. The contrast between vessel-to-background was low in the low FA MOTSA, whereas the contrast increased when RF pulses with high FA were adopted. However, the venetian blind artifact became severe in the high FA images due to the rapid signal saturation. On the other hand, the MIP results from the sliding TOF exhibit high vessel-to-background contrast without venetian blind artifacts.

Conclusions

In conventional MOTSA, there is a tradeoff between vessel-to-background contrast and venetian blind artifact. On the other hand, the proposed sliding TOF can provide high contrast angiogram without venetian blind artifact by adopting the sliding slab sampling scheme and the tornado filter. Furthermore, SNR of the proposed algorithm is higher than those of conventional Cartesian MOTSA techniques due to the use of radial trajectory. In conclusion, the proposed sliding TOF could become a useful TOF angiography method as successfully demonstrated by the angiography experiments performed in this study.

References

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Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST) (No. 2012-0000125).

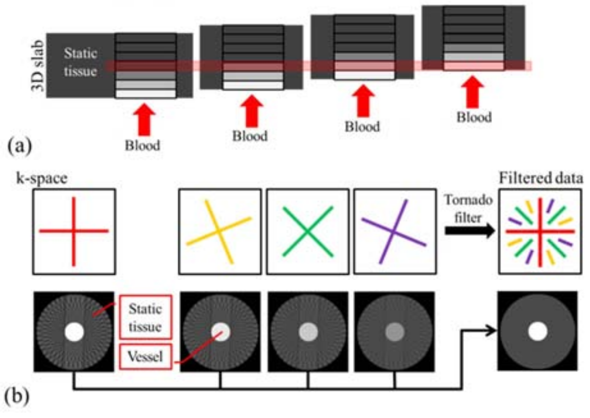

Figure 1. (a) The data acquisition scheme for the sliding TOF. The distance between adjacent slabs is equal to slice thickness. (b) Reconstructed images from subsampled data contain severe streaking artifacts and signal intensities from blood are different according to the slice position. The high contrast without streaking artifact image can be reconstructed by tornado filtering.

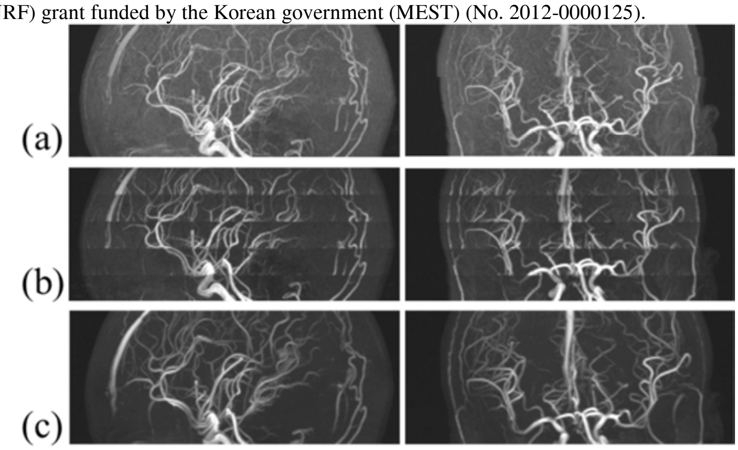

Figure 2. TOF MIP results from conventional MOTSA (18°and 38°) and the sliding TOF (38°). Because of the low flip angle (18°), the contrast between vessel and background tissues is low in row (a). In the high flip angle (38°), the contrast increases in row (b). However, venetian blind artifacts were severe in the conventional MOTSA. On the other hand, due to the sliding sampling scheme and the tornado filtering, (c) the results of sliding TOF show high contrast images without venetian blind artifacts.