Application of 3D High-resolution Multi-echo TOF-SWI Acquisition in Radiation-induced Cerebral Microbleeds at 3T

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Introduction:

Radiation therapy (RT) is a widely utilized treatment in the management of patients with gliomas. Despite its effectiveness and advances in modern technology to deliver constrained dose distribution to the tumor, RT can result in collateral injury to normal-appearing brain tissue, such as the formation of cerebral microbleeds (CMBs) [1-3]. The ability to assess characteristics of CMBs in conjunction with the surrounding arterioles and venules would help to identify underlying vascular injury. Recently, an integral multi-echo acquisition of 3-D time of flight (TOF) MR angiography (MRA) and susceptibility-weighted imaging (SWI) MR venography (MRV) has been demonstrated in healthy volunteers at 3T using four echoes[4, 5]. An adaption of this multi-echo sequence that was optimized for 7T has shown that the composite SWI images from multiple echoes can achieve higher resolution with increased detection sensitivity to radiation-induced CMBs[6]. Although implementation of such a sequence on more widely available 3T scanners comes with the tradeoff of reduced sensitivity, the longer echo times required for SWI at 3T permits the acquisition of additional earlier echoes that can be utilized to generate overlayable multi-contrast maps obviating the need of extra scans and image registration. The goal of this study was to determine an optimal acquisition and reconstruction strategy for multi-echo multi-contrast high-resolution vascular imaging at 3T within a clinically feasible scan time. We hypothesize that additional contrasts, such as R2*, would potentially facilitate routine clinical evaluation of CMBs.

Methods:

Acquisition: A multi- echo sequence with seven echoes was created from a commercially available multi-slab 3-D TOF sequence. Although a TONE pulse is typically employed to compensate TOF signal saturation in slice direction, it degrades SWI contrast and complicates brain tissue signal[5]. As an alternative compensation strategy, we used thinner slabs of 24 slices and performed flow compensation only in readout direction to minimize the first echo time. To achieve similar resolution as 7T and maintain reasonable signal to noise ratio (SNR), the slice thickness was kept at 1 mm while a rectangular in-plane FOV of 24x18 cm^2 with matrix size 384 x 288 was used. 4 axial slabs with 24 slices and 4 overlap slices were prescribed to cover the entire supratentorial brain. All seven echoes were 66.25% partially acquired with 41.67kHz readout bandwidth. The resultant echo times and repetition time were TE1/ TE2/ TE3/ TE4/ TE5/ TE6/ TE7 = 2.4/ 12.0/ 14.3/ 20.3/ 22.6/ 28.6/ 31 ms and TR = 39 ms. To reduce the scan time, an autocalibrating partially parallel acquisition[7] was applied in phase encoding direction with an acceleration factor of 2 and 24 autocalibrating line. The total scan time was 10:43 min. Three patients with glioma who had received RT 2- 15 years prior were scanned on 3T Discovery MR 750 GE scanner using 32-channel head array coil.

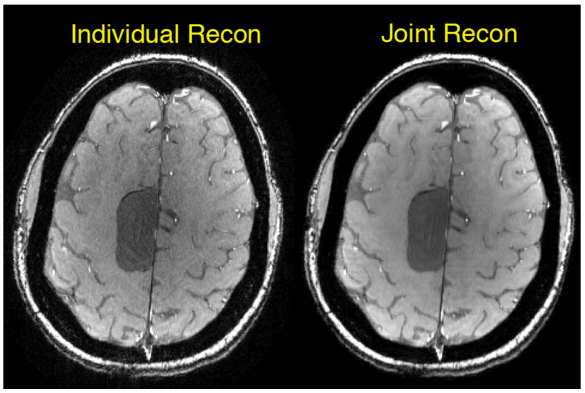

Figure 1: Comparison of individual echo reconstruction and joint reconstruction of the last six echoes. Magnitude images of 4th echo shows SNR gain in joint recon.

Reconstruction: TOF MRA images and composite SWI MRV images reconstruction was similar to the previously described pipeline [6]. TOF MRA images were created from the first echo and composite SWI MRV images were created by from the remaining six echoes. To accommodate different phase wrap severity at different TEs, the sizes of symmetric Hanning filter used in homodyne filtering the six SWI echoes were 34, 40, 54, 60, 76, and 82, respectively. The magnitude images of the six SWI echoes were jointly reconstructed [8] to increase SNR (Fig. 1). At the end, R2* images were obtained by mono-exponentially fitting individually reconstructed magnitude images of all seven echoes using a nonlinear least squares algorithm.

Results

Maximum-intensity projection (MIP) TOF from one patient is displayed in fig. 2 along with SWI and R2* images of one slice from the same patient. Four CMB candidates as rounded foci of low intensity were observed in SWI images. Three of them (red arrows) were true CMBs counted by an automated CMB detection algorithm[9] and corrected by an experienced rater. The other one (yellow arrow) was a cystic change verified by separate FLAIR images. Their diameters on the composite SWI images were approximate 1~2 mm (2~3 in-plane voxels). The high-resolution R2* map successfully differentiated the true CMBs as bright spots and the cystic change as a dark spot at exactly the same positions, demonstrating a potential benefit of simultaneous high-resolution multi-contrast maps to assist CMB detection without possible errors introduced by co-registration.

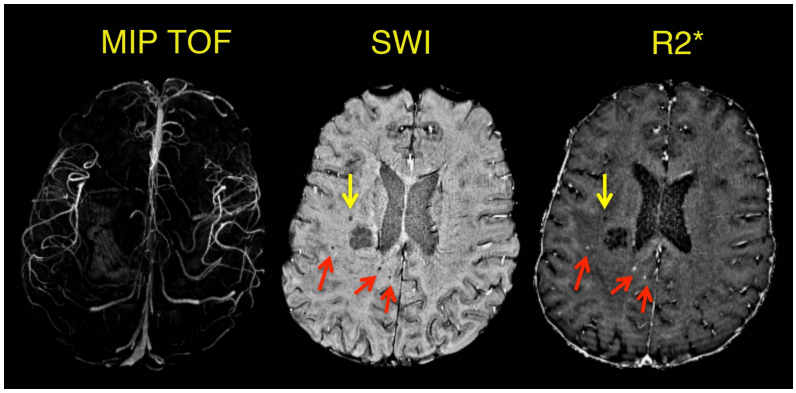

Figure 2: Exemplary reconstruction results. Three microbleeds (red arrows) and one cystic change (yellow arrow) were observed on the SWI and R2* map

Discussion

Many factors need to be considered when optimizing multi-echo multi-contrast TOF-SWI sequences. In addition to image resolution, slice/slab thickness, and parallel image acceleration, the trade-off between bandwidth and the number of echoes has significant impact on SNR and the accuracy of multi-parametric measurements. A greater number of echoes not only allows for R2* fitting but also quantitative susceptibility mapping which may be more helpful in assessing CMB burden[10]. In this preliminary study, the proposed seven-echo sequence showed adequate contrast in MIP TOF, SWI, and R2*. Using seven echoes, the R2* map revealed a potential benefit of multi-contrast imaging in CMB discrimination, at a cost of SNR due to relatively high bandwidth. However, the depressed SNR of the individual echo images is partially regained by averaging to generate the composite SWI images [6]. The SNR was further improved by exploiting the redundancy between multiple echoes in the joint reconstruction. Future work will further optimize the reconstruction and quantitatively compare the sequence with standard alone TOF and MRV sequence. The clinical relevance of derived multi-parametric maps will also be evaluated.

References

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