Parallel imaging accelerated susceptibility imaging with no SNR penalty

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Introduction Quantitative susceptibility mapping potentially allows the in vivo tissue composition to be quantitatively assessed. Conventionally, susceptibility maps are calculated using the phase information obtained using 3D gradient echo sequence with a Cartesian sampling, i.e. 3D SPGR. Due to the long echo time used and the high resolution desirable, data acquisition covering a sufficiently large brain volume takes considerably long. Fast imaging sequence such as spiral has been proposed (1). However such sequence is usually not available on commercial scanners and is also sensitive to susceptibility variations that lead to image aritfacts. On the other hand, parallel imaging as a widely accepted imaging acceleration method, is usually associated with degraded SNR. Although additional post processing may be applied to remove the incurred noise enhancement, it may also introduce additional artifacts in the reconstructed images (2). In this work, we propose to utilize the otherwise wasted empty echo space to make additional echo acquisitions, and use the SNR gain from multi-echo phase averaging to compensate for the SNR loss in parallel imaging.

Theory As shown in (1), the resulting SNR improvement of the multi-echo averaged phase map as compared to that at a single echo time is:

$$\frac{SNR_{ME}}{SNR_{SE}} = \frac{N}{0.37t_2^*\sqrt{\sum_{n=1}^{N}\left(t_n e^{t_n/t_2^*}\right)^{-2}}} \quad [1] \qquad \frac{SNR_{PI}}{SNR_{full}} = \frac{1}{g\sqrt{AF}} \quad [2]$$

where t_n is the echo time of the nth echo acquisition and t_2^* is the T2 star of the tissue of interest. Assuming a t_2^* of 40ms (white matter) and total of 16 echo acquisitions starting at 8ms with an echo spacing of 2.1ms, multi-echo averaging leads to a SNR improvement factor of about 4 in the resulting phase map. This SNR gain factor is then in theory able to offset the SNR loss from parallel imaging (given by [2]) at an acceleration factor of 4, assuming a moderate g-factor of 2.

Method In vivo brain imaging of a healthy adult volunteer was performed with a GE 3T 750 scanner equipped with an 8 channel head coil. In a typical susceptibility imaging protocol with 3D SPGR (TE/TR = 40/50ms, FA = 20, matrix size = 192x192x120, FOV = 19.2x19.2x12cm), we inserted additional 15 echoes in the front of the original echo at TE = 40ms as shown in Fig.1: minimum TE = 8 ms, echo spacing = 2.1ms. Full k-space data sets at the 16 different TEs were acquired. Then parallel imaging reconstruction (GRAPPA) at AF = 4 was performed for dataset at each TE using the central kspace of 16x16 as calibration, which gives a net acceleration factor of 3.8. The susceptibility maps were then derived from the reconstructed images as in (1). We compare the susceptibility map derived from the fully sampled dataset at TE = 40ms, the GRAPPA accelerated dataset at TE =40ms and the GRAPPA accelerated dataset with multi-echo phase averaging.

Results An axial plane slice of the calculated susceptibility map from the fully acquired data set, parallel imaging accelerated single echo and multi-echo susceptibility map are compared in Fig 2. It is seen that the GRAPPA accelerated acquisition leads a degraded SNR in the resulting susceptibility map (Fig.2.(b)), whereas the multi-echo averaging results in a much improved SNR in the phase map and it in turn gives a susceptibility map with a much higher SNR (Fig.2.(c)). Visually it shows a SNR even better than that corresponds to the fully sampled data set at TE = 40ms in some regions (as arrowed). We also compared the quantitative susceptibility measurements of different nuclei regions as shown in Table 1, it is seen that the multi-echo data set gives susceptibility measurements that is much closer to those of the fully sampled data set.

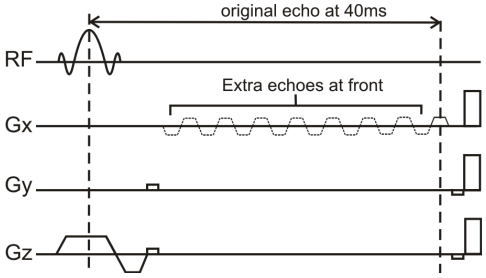

Figure 1: 16 echo SPGR acquisition with a minimum TE of 8ms and an echo spacing of 2.1ms

x 0.01 ppm	TE = 40ms fully sampled	TE = 40ms AF = 4	Multi-echo AF = 4
GP	5.8	5.1	5.6
PU	2.3	3.2	2.7
RN	7.8	8.2	7.9
SN	6.9	5.8	6.6

Table 1: susceptibility Measurements of selected deep nuclei regions of fully sampled single echo acquisition, GRAPPA accelerated single echo and multi-echo acquisition.

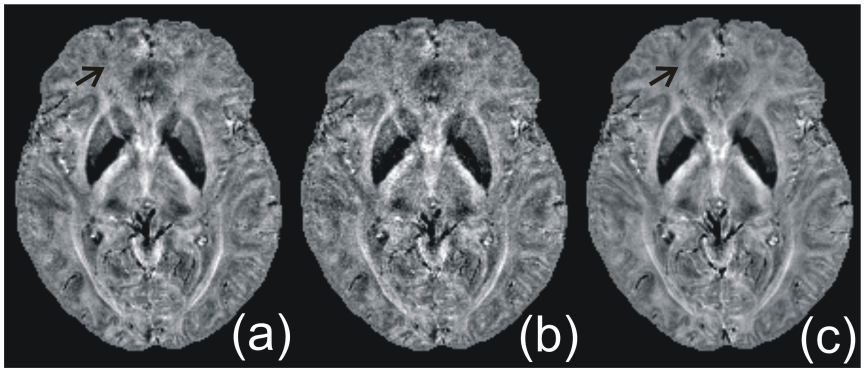

Figure 2: Axial plane of the susceptibility map derived from (a) fully sampled data set at TE = 40ms; (b) GRAPPA accelerated acquisition at AF = 4 at TE = 40ms; (c) GRAPPA accelerated acquisition with 16 echo acquisitions.

Conclusion We have shown, both qualitatively and quantitatively, the SNR improvement gained through multi-echo averaging may be used to compensate for the SNR loss incurred in parallel imaging. This potentially allows susceptibility imaging with SGPR to be completed within a clinically feasible time frame with no SNR penalty. Compared to other means of noise reduction in parallel imaging, the multi-echo averaging method introduces no extrinsic artifacts. Unlike other fast imaging sequence, this method may be ready implemented on the scanner.

Reference (1) Wu, et al., Neuroimage 2011 (2) Wu, et al, ISMRM 2011, #4474