Phase Corrected Bipolar Gradients in Multiecho Gradient Echo Sequences for Quantitative Susceptibility Mapping

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Quantitative susceptibility mapping (QSM) has recently received increased scientific and clinical attention due to its promising potential applications. Singe echo and multiecho gradient-echo (GRE) sequences can be used to obtain the field map for QSM. The multiecho GRE sequence offers the benefit of simultaneous acquisition of all echo times in one excitation, leading to a higher SNR and a wider range of sensitivity to susceptibility than single echo approach[1]. Furthermore, the temporal evolution information in the multiecho approach enhances the robustness of the unwrapping algorithm on the estimated field map[2]. To ensure phase consistency among the echoes, multiecho QSM usually uses the unipolar gradients to acquire all echoes. However, compared with bipolar gradients approach, the unipolar gradients in multiecho sequences result in not only less efficient data acquisition but also longer echo-spacings. In this study, we aim to demonstrate the feasibility of generating a quantitative susceptibility map in human brain imaging from bipolar multiecho GRE sequence with linear phase correction in read-out direction.

Material and Method

Eight healthy volunteers (age: 22–44 years) participated in this study with informed consent and IRB approval. 3D multi-echo gradient-echo data were acquired on a 3T MRI system using a unipolar sequence (as the reference standard) and a bipolar sequence (newly developed) with the following imaging parameters for both sequences: TR=43ms, TE1=3.19ms, RBW=360Hz/pixel, FA=15°, Matrix=256×232×64, spatial resolution =0.93mm×0.93 mm×2.0 mm. Number of echoes was maximized and echo spacing ΔTE was minimized separately for unipolar and bipolar gradients: 8 echoes with ΔTE=4.4ms for uniopolar, and 12 echoes with ΔTE=3.19ms were used for bipolar. Both sequences were repeated twice, allowing for the evaluation of the local noise standard deviation from the subtraction of the two acquisitions .

For the bipolar gradient, phase shift of even echoes induced by gradient delay and eddy current were estimated and corrected with a linear phase correction in the read-out direction[2,3]. QSM images were obtained from phase data using the Morphology Enabled Dipole Inversion (MEDI) algorithm[4]. Five regions of interest (ROIs) (caudate nucleus, globus pallidus, putamen, red nucleus and the substantia nigra) were manually drawn on central slice depicting unambiguously these structures on QSM images using ITK-SNAP. The noise of the QSM locally for each ROI was defined as the standard deviation of the difference between the repeated acquisitions .

Results

In the ROI-based quantitative susceptibility comparison, the slope of the linear regression between bipolar and unipolar was close to unity and the intercept was close to zero. The correlation coefficient was also close to 1, indicating a good agreement between the bipolar and unipolar susceptibility measurements (Fig. 1B). The Bland-Altman plot exhibited no significant bias or trend between bipolar and unipolar. The 95% limit of agreement between bipolar and unipolar was -0.024 to 0.027 ppm over the range of approximately 0.02 to 0.22ppm (Fig. 1C). Figure 2 shows bar chart of the measured noise. It can be assessed that the use of bipolar multiecho acquisition leads to a noise reduction for all subjects and all ROIs. On average, this noise reduction ranges from 13.7% for the caudate nucleus to 27.9% for substantia nigra.

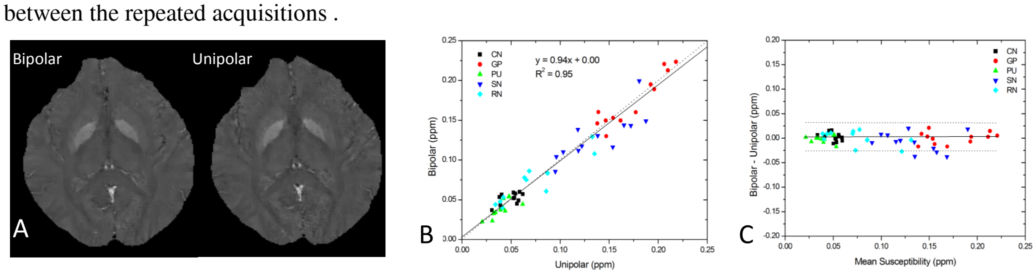

Fig. 1. Qualitative and quantitative comparison mean susceptibilities in deep nuclear between bipolar and unipolar (A:QSM slices from the same volunteer; B: linear regression; C,Bland-Altman analysis). The solid and dotted lines in B are the trend line of the linear regression and the line of equality, respectively. The solid and dotted lines in C indicate the mean difference ±1.96× the standard deviation of the difference, respectively.

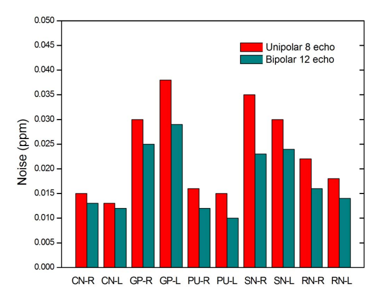

Fig. 2. Bar chart comparison of the QSM noises in different brain regions with between bipolar and unipolar

Discussion and Conclusions

Multi-echo sequences using bipolar readout gradients are attractive due to their efficient data acquisition scheme, however this acquisition scheme requires correction for phase errors. In this paper, we investigated the feasibility of generating a quantitative susceptibility map in human brain imaging from bipolar multiecho GRE sequence with a linear phase correction in read-out direction. A good quantification agreement was found between the bipolar and unipolar gradient techniques, indicating that the bipolar technique is a suitable option for QSM.

In this paper, only linear phase correction in readout direction was applied to the bipolar data. Phase correction with higher order errors and in all three spatial directions may further improve the accuracy of field map estimation, which have been demonstrated to be important to fat quantification using multiecho sequences with bipolar gradients[5,6].

References

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