Slice-specific navigator correction for multiband imaging

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Target Audience: Investigators using slice-accelerated acquisitions - where multiple slices are acquired simultaneously - and developers of reconstruction algorithms.

Purpose: The use of Cartesian EPI with multiband imaging (SMS) {1-3}means that slices with very different B0 fields, and as such different echo-shift between even and odd readouts are acquired simultaneously{3}. Under good shimming conditions or for nearly adjacent slices the echoes from the spatially different slices are almost aligned with a singular correction, and has limited residual ghost. For more common applications, the variability in B0 lends itself towards residual ghosting and thus the developments of techniques for ghost-correction in multiband imaging are receiving increased attention.

Introduction: In {3} it was proposed to use a multiband separation algorithm "slice-GRAPPA" to independently separate the even and odd echoes and then subsequently apply the slice-specific echo-shift correction calculated from the acquired navigator. The approach has been successful, but one challenge is that the slice-GRAPPA algorithm when applied to only either the even or the odd echoes have an effective in-plane undersampling of 2, which means higher g-factors when performing the slice-separation. Relying instead on a SENSE type reconstruction, the signal model can be extended to include the slice specific echo-shifts, however this requires the calculation of sensitivity profiles, -which can be more challenging for some applications.

Methods: Highly accelerated multislice GE-EPI studies were acquired on a modified 3T Skyra scanner (Siemens Healthcare, Erlangen, Germany) with MB 8 and a FOV/3 shift between adjacent slices and 2mm isotropic resolution data {4}. The relative echo-shift was estimated from the phase of a three-line navigator as shown in Fig 1.(middle). Using a linear polynomial fit, the echoshift was estimated for each slice, Fig 1 (right). Reconstructions were performed offline in Matlab and compared with the online DICOM result which is a version of slice-GRAPPA with the multiband navigator used for correction (which is similar to the average $\sum \varphi_i$ navigator). The offline multiband data was tested with the target-slice specific navigator φ_i, and the average $\sum \varphi_i$. After multiband separation with the average, it was tested if the slice-specific echo correction $(\varphi_i - \sum \varphi_i)$ can be applied to the slice-separated signals. The reconstruction was performed both with slice-GRAPPA{3} and a RO extended SENSE/GRAPPA {5,6} algorithm.

Results and Discussion: In Fig 1. it can be appreciated that a linear polynomial fit to the navigator phase provides a reasonable estimate of the echo-shift. In Fig 2A, top and bottom rows, the online reconstructions are shown with different gray-scale levels. The selected images highlighted are used for comparison of the different reconstruction options. From the bottom row, residual ghosts can be appreciated at a level comparable to Fig2C which is the online implementation. The approach with the lowest ghosting level is the RO Extend SENSE/GRAPPA reconstruction, where the multiband data are echo corrected with the target slice-optimal shift prior to separation.

Conclusion: Residual ghosting is a challenge for multiband EPI. We show that the aliasing can be reduced the most by applying a slice optimal correction prior to separation integrated with the RO Ext. SENSE/GRAPPA algorithm, Fig 2F . For an MB=N dataset, this implies that the acquired data has to be un-aliased N times, each time with a different echo-shift. The slice-GRAPPA algorithm FIG2G has a higher ghosting level, but is computationally more efficient. For the RO Ext. SENSE/GRAPPA algorithm, all the slices are un-aliased simultaneously, whereas the slice-GRAPPA algorithm un-aliases each slice separately. For the slice-GRAPPA algorithm benefits can be achieved when applying an additional correction after slice-separation of the signals, but this is not stable across all slices, as evidenced in the superior slice from Fig 2C and Fig 2E.

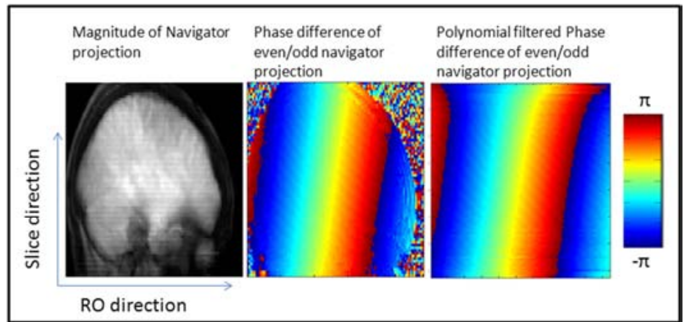

Fig1: Navigators. Middle figure is the phase difference between even and odd navigator, and the right is the phase after polynomial fitting.

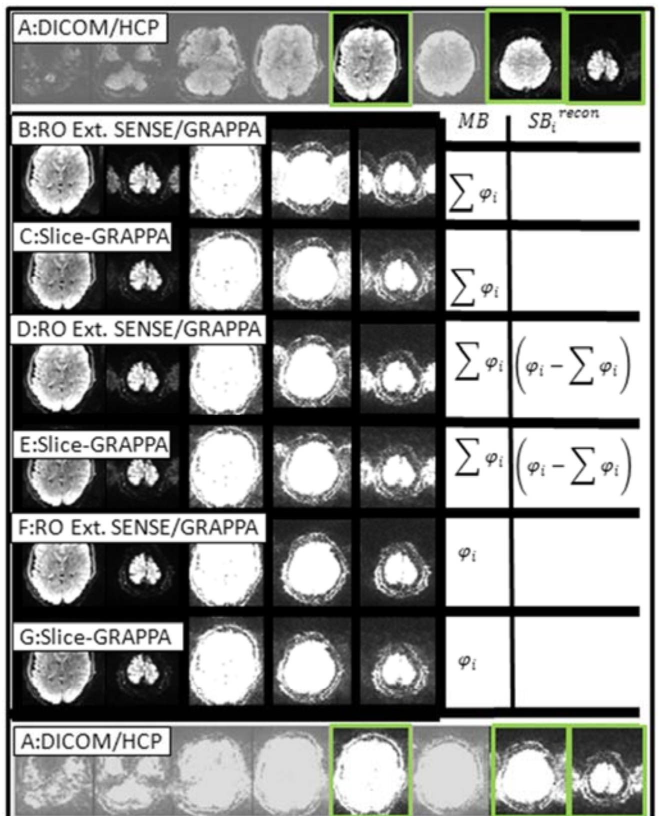

Fig2: Reconstruction. A is online reconstruction. The two rightmost columns indicate which phase is applied to the Multiband before un-aliasing, and which is applied after un-aliasing. Only select slices from an MB8 acquisition are shown, and with different gray levels.

References: 1.[Larkman, JMRI, 2001], 2.[Moeller, MRM 2010], 3.[Setsompop, MRM 2012], 4. [Ugurbil, Neuroimage 2013], 5. .[Breuer, MRM 2005], 6.[Moeller, ISMRM 2014, submitted]

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