Simultaneous multi-slice imaging in combination with phase-sensitive parallel MRI

Morwan Choli[1], Felix A. Breuer[1], Peter M. Jakob[1,2], and Martin Blaimer[1]
[1]*Research Center Magnetic Resonance Bavaria e.V (MRB), Wuerzburg, Germany,* [2]*Department of Experimental Physics 5, University of Würzburg, Wuerzburg, Germany*

Introduction: Shorter scan times in MRI can be achieved by simultaneously exciting multiple slices. The individual slices can then be separated by applying dedicated parallel MRI algorithms [1]. The benefit over standard parallel MRI is an increased signal-to-noise-ratio (SNR) because a larger volume is excited. However, a reliable slice separation requires sufficient coil sensitivity variations along the slice direction. This requirement may not be met for closely spaced slices and hence the image quality may suffer from noise amplification due to high geometry factors. To overcome this problem, it has been proposed to improve the conditions for the parallel MRI reconstruction by shifting the individual approaches with respect to each other [2]. However, this approach requires dedicated RF phase-cycles and does not work for single-shot sequences such as EPI or HASTE.

In this work, we present an alternative approach for simultaneous multi-slice imaging by including phase information about the excited slices in the parallel MRI reconstruction. The underlying idea is to provide phase difference between excited slices (Fig. 1) and to include this information about phase difference in parallel MRI reconstruction for improved slice separation. In that way, (1) even closely spaced slices can be reconstructed with high quality and (2) single-shot experiments with simultaneous multi-slice excitations become feasible, since no special RF phase cycles are required.

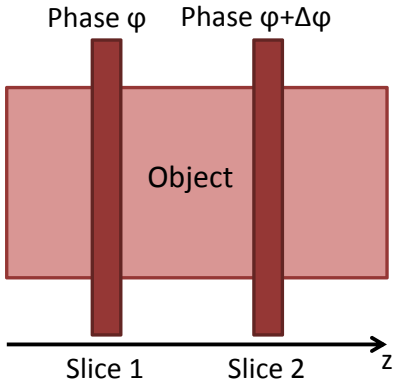

Figure 1: Phase difference $\Delta\phi$ between simultaneously excited slices is used to improve image reconstruction.

Materials and Methods: Imaging experiments were performed on a healthy volunteer using a clinical 3T scanner. For proof of principle a FLASH sequence was used to provide two reference slices and coil sensitivities of a 20 channel head coil. Simultaneous multi-slice imaging was performed with a FLASH sequence with the same parameters but with a dual-band RF-Pulse to excite two slices simultaneously. The FLASH parameters were as follows: TR = 40ms, TE = 4 ms, Matrix: 256x256 and slice thickness of 3.5 mm slice separation 10.5 mm. The Phase difference between the two simultaneous excited slices of $\Delta\varphi=90°$ was chosen, because it provide the ideal phase variation for a unique separation of two closely spaced slices when there are no coil sensitivity variations.
The slices were separated using a standard parallel MRI algorithm (GRAPPA). In addition, a phase-sensitive GRAPPA reconstruction was performed by generating additional virtual channels that include the conjugate-symmetric signals of the real channels [3]. In that way, the additional phase-difference between individual slices is taken into account in a standard parallel MRI reconstruction process.

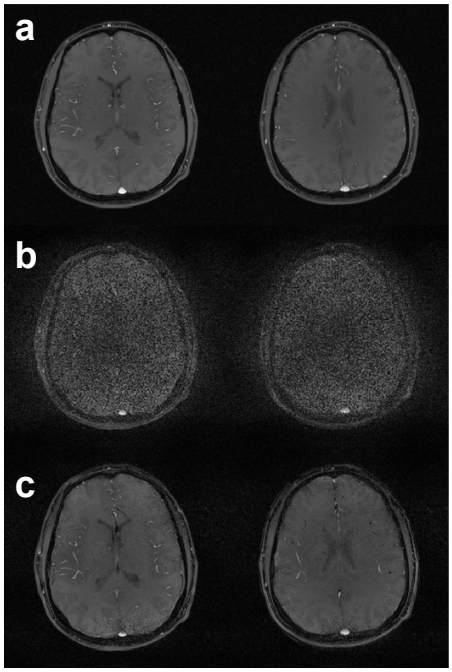

Figure 2: (a) reference scan, (b) conventional GRAPPA and (c) phase Sensitive GRAPPA scan of a human head.

Results: Figure 2a shows two in vivo reference images of a human brain. Fig 2b presents the TWO-SLICE GRAPPA reconstruction of the two simultaneously excited slices. Image quality is severely degraded by strong noise enhancement due to insufficient coil sensitivity variations between slices. Fig 2c shows the phase sensitive GRAPPA reconstruction using the virtual coil concept allowing for separating the two slices without visible noise enhancement.

Discussion: It has been shown that the phase information about the simultaneously excited slices can be included in the parallel MRI reconstruction. In addition to coil sensitivity variations, phase variations are used to separate the individual slices. High quality reconstructions for even closely spaced slices have been presented. For future application, reduced power pulses for simultaneous multi-slice excitation [4] make this approach interesting for efficient high-field imaging with improved SNR as compared to standard single-slice parallel MRI also for single-shot sequences (e.g. HASTE) this technique can be used.

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References:

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