Slice-specific frequencies can reduce ghosting artifacts in T2*-weighted single-shot EPI with GRAPPA

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Introduction

Echo-planar imaging (EPI) [1] is an important tool for functional imaging of the brain but it is sensitive to imaging artifacts like geometric distortions in the presence of field inhomogeneities, e.g. in regions close to significant susceptibility differences as in the vicinity of major air cavities: Parallel imaging techniques like GRAPPA [2] reduce these distortions significantly by acquiring a smaller field-of-view and are widely used in functional neuroimaging today. However, in GRAPPA the unaliasing required to obtain the desired field-of-view seems to be sensitive to frequency offsets yielding residual aliasing or ghosting in the images. Here, it is shown that these artifacts can be reduced or even avoided with a slice-specific frequency for the data acquisition, i.e. the frequency and phase settings of the analog-to-digital converter (ADC).

Methods

The standard FID-EPI pulse sequence of the manufacturer was extended to consider a slice-specific, user-selectable frequency during the data acquisition. It involved (i) a manipulation of the ADC's frequency to use a slice-specific demodulation frequency for all echoes of the slice and (ii) a corresponding manipulation of the ADC's phase settings for the individual echoes of an echo train such that the linear phase modulation occurring for the frequency offset along the echo train is corrected for.

Measurements were performed on a 3T whole-body MR system (TIM Trio, Siemens Healthcare) using 12-channel (phantom) and 32-channel (in vivo) head coil (both receive-only). T2*-weighted FID-EPI was acquired with a voxel-size of $2\times2\times2mm^3$ and a repetition time of 3 s. 6/8 partial Fourier encoding or GRAPPA [2] with an acceleration factor of 2 (24 reference lines) was applied to achieve an echo time of 30 ms. A water phantom and healthy volunteers were investigated after their informed consent was obtained. To demonstrate the influence of a frequency offset, some measurements were performed with the MR system frequency shifted.

Results and Discussion

Figure 1 demonstrates the basic problem in a phantom. Without an offset of the MR system's frequency, both techniques, partial Fourier and GRAPPA, reveal a good image quality and do not exhibit ghosting (Fig. 1a). With a frequency offset, the images obtained with partial Fourier are almost unaffected while those acquired with GRAPPA show significant ghosting (Fig. 1b). However, using a corresponding offset for the frequency used during the data acquisition, the ghosting of the GRAPPA acquisitions disappears (Fig. 1c). This can also be seen in in vivo measurements in Fig. 2. As long as all slices share the same MR frequency, such ghosting artifacts are avoided by a correct adjustment of the MR system's frequency. However, in a large stack of slices, the signal frequency may vary between slices while the MR system's frequency is set to a fixed value for all slices. Thus, ghosting can become relevant, in particular in slices in the upper and lower brain where field inhomogeneities can shift the signal frequency. Then the usage of a slice-specific frequency for the data acquisition, i.e. manipulating the frequency and phase settings of the ADC appropriately, can reduce ghosting artifacts as is shown in Fig. 3.

The reason for the ghosting artifacts could be the different effective echo spacings for the GRAPPA reference scan that covers all k-space lines, and the image acquisition where k-space lines are skipped. Thus, adapting the GRAPPA reconstruction algorithms could also solve the problem and may be easier to impement than the current approach. In a more general solution different frequencies could be utilized by the MR system for different slices which could also address the adaptation of the frequencies used, e.g., for the fat saturation. However, as long as the same system frequency is used for all slices on an MR system, the presented approach could be considered as a work-around to reduce related artifacts.

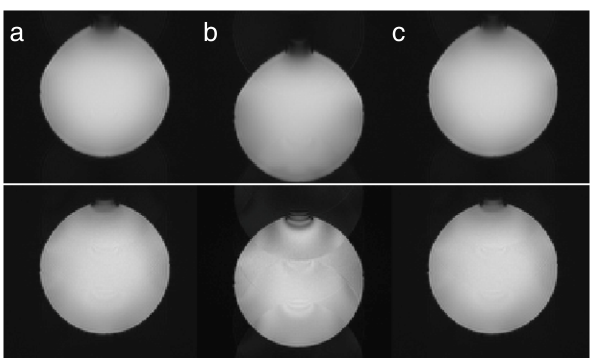

Fig. 1: An isocentric slice in a phantom acquired with partial Fourier (upper) and GRAPPA (lower). In (a) the MR system frequency was correctly adjusted, in (b) and (c) it was shifted by −200 Hz. (b) was obtained without, (c) with correspondingly adapted ADC settings, i.e. a frequency offset for all echoes and a phase linearly modulated along the echo train. The apparent phantom shift in (b) is due to the linear phase evolving along the echo train which is corrected for in (c).

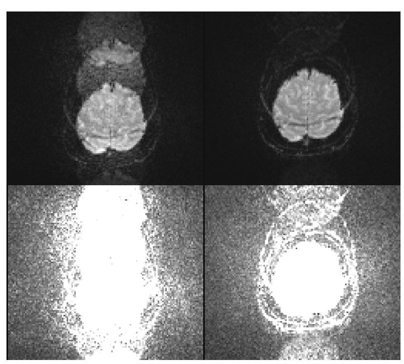

Fig. 2: In vivo example for the ghosting introduced in EPI with GRAPPA by a system frequency offset without (left) and with (right) a corresponding adjustment of the ADC settings (see Fig. 1). The lower row repeats the upper row with a different gray scaling

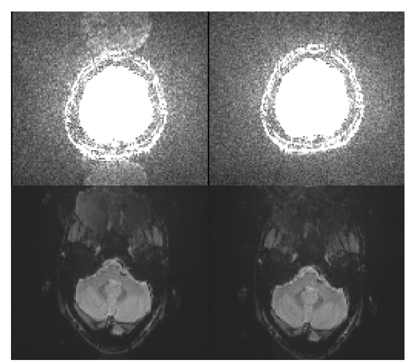

Fig. 3: In vivo examples with the MR system frequency adjusted to the full stack of slices. Residual ghosting occurs in upper and lower slices (left). It is reduced when using a slice-specific frequency setting for the data acquisition, i.e. frequency and phase settings for the ADC.

References

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