Improving image quality of bSSFP with centric k-space trajectory

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INTRODUCTION: Balanced steady-state free precession (bSSFP, TrueFISP, FIESTA, b-FFE) image quality relies on a constant phase increment which the magnetization experiences between consecutive sequence cycles. Artefacts appear in the image if the phase is disturbed by eddy currents induced by field gradient switching. Especially for centric k-space reordering eddy currents cause a smearing of the image in phase encoding direction. We propose a method based on the work of Bieri and Scheffler [1] to remove this artefact while total acquisition time and image efficiency is nearly kept constant. The idea is to use inner averaging in combination with parallel imaging.

METHOD: Field gradient switching causes a change d*B*/d*t* in magnetic flux, thereby inducing eddy currents on the conducting parts of the scanner system (coils) or in the patient, where they can cause field variations and physiological stimulation. The eddy currents cause spatially varying phase errors for the magnetization. After some repetitions of the sequence cycle the eddy current pattern will reach a steady state, thus causing mainly constant phase offsets which do not severely influence image quality [2]. For a linear k-space line ordering the steady-state of the eddy currents is reached when k-space-center data are collected and the PSF of the k-space filter due to eddy currents causes only a very slight decrease of image resolution. For a centric k-space line ordering, the eddy currents develop not in a constant manner for the first sequence cycles when k-space center is encoded. This will result in low-frequency k-space errors which will lead to visible artefacts in the image. A method called "double-cycle" was proposed [1], which collects two adjacent k-space lines before a jump in k-space is carried out. This will lead the phase errors to be about equal for two consecutive sequence cycles as the RF–pulse phase is incremented by 180° in standard bSSFP. Thus, images show improved quality, but some artefacts remain. We propose to modify the double-cycle pattern in a quite simple way in order to achieve further artefact reduction: Instead of recording paired k-space lines, one can use inner averaging, which records each line twice and adds up the two signals before increasing the phase encoding gradient. This setup guarantees a complete cancelling of the eddy current induced phase errors, the artefact in phase encoding direction is further decreased. Compared to the double-cycle scheme, inner averaging requires twice the scan time but improves SNR by $\sqrt{2}$. The scan time can be set back to the value the double-cycle scheme needs by using GRAPPA. This means, bSSFP image quality for centrically reordered k-space trajectories can be significantly improved by taking two inner averages while the total scan time and SNR can be maintained by using GRAPPA.

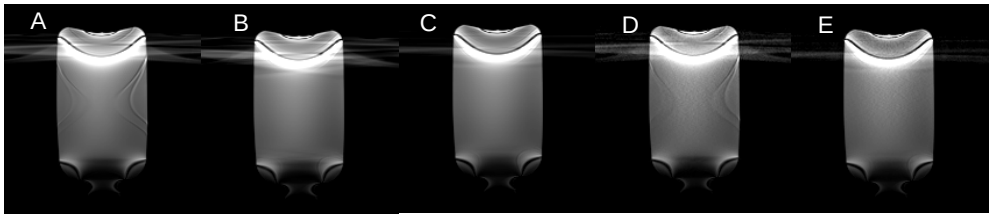

Fig. 1: 2D bSSFP phantom images on 3T, coronal view. A: centric reordering (scan time 1.14 s). B: double cycle. C: centric reordering, 2 averages. D: centric reordering, GRAPPA. E: centric reordering, GRAPPA, 2 averages (scan time 1.25 s)

RESULTS: Two different Sets of 2D images are shown: 1. Coronal phantom images on 3T (Siemens Trio) to show the artefact behaviour of different acquisition schemes (Fig.1). 2. Transversal in vivo images (head) on 1.5T (Siemens Sonata) of a healthy volunteer (Fig.2). Parallel imaging was realized with a GRAPPA factor of two and 32 reference lines. SNR analysis was carried out on transversal 2D images on 1.5T with a ball phantom and optimized shim (data not shown). SNR of GRAPPA images with two averages and images without GRAPPA and without averaging are about equal. Phantom images on 3T are shown in Fig. 1. Compared with the centric k-space reordering, the double cycle image shows less artefacts in the phantom. Near the location of the typical dark bSSFP stripe where the resonance offset leads to a dephasing angle of about 180° during TR, the eddy current induced artefacts become even worse. Also a suitable windowing would reveal a slight N/2 ghost in the double cycle image. The GRAPPA images with centric reordering show similar artefact behaviour as the images without GRAPPA do. The fewest artefacts are in the image with centric reordering and two inner averages. The remaining artefacts near the dark stripe are due to off-resonance signal oscillations. If the scan time and image efficiency has to be kept on a certain value and a centric line ordering is used, it is therefore advisable to use GRAPPA in combination with inner averaging.

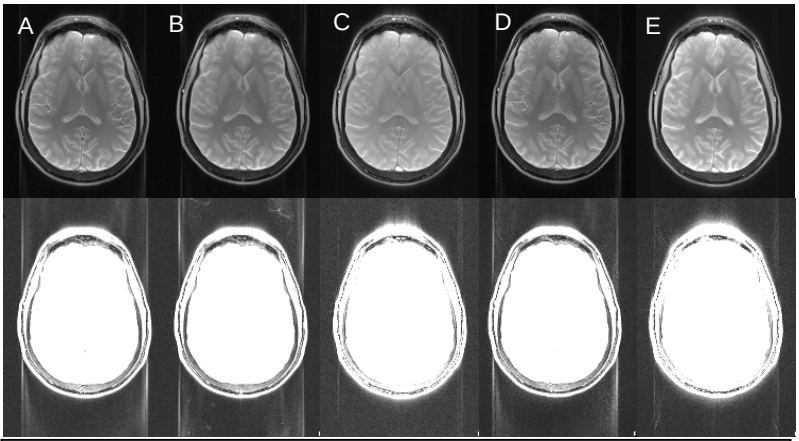

Fig. 1: Axial 2D bSSFP head images on 1.5T. A: centric reordering. B: double cycle. C: centric reordering, 2 averages. D: centric reordering, GRAPPA. E: centric reordering, GRAPPA, 2 averages. Bottom row: enhanced windowing to make artefacts visible.

CONCLUSION: The proposed method of using GRAPPA in combination with inner averaging yields images nearly without eddy current artefacts for centrically reordered k-space trajectories. Compared to the double-cycle method the artefacts are further reduced. In principle it is possible to reduce the eddy current artefact for arbitrary k-space trajectories by using inner averaging. A practical advantage is the easy availability of the proposed method, as standard implementations of bSSFP support parallel imaging and inner averaging. The final image quality depends still on the specific setup of parallel imaging, e.g. coil sensitivity maps, robustness of the reconstruction algorithm or the number of used reference lines.

REFERENCE: [1] Bieri and Scheffler, Proc. Intl. Soc. Mag. Reson. Med. 11 (2004), Nr.104. [2] Foxall DL, MRM 2002;48:502-508.