Chimera Averaging for Robust SSFP Magnetization Transfer Contrast Imaging (MT-Chimera)

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Introduction

Recent studies [1] revealed that balanced SSFP shows a pronounced magnetization transfer (MT) contrast, which can be altered via the RF pulse duration and thus allows for quantitative MT imaging [2]. It is thereby assumed that changes in signal intensity are due to the MT effect alone. However, elongated RF pulses entail a prolonged TR, which may introduce signal variations due to the frequency response of balanced SSFP (banding). This obstacle may be tackled by very accurate shimming or frequency offset averaging (OA) [3]. A novel OA approach is investigated in the present study. A linear averaging method based on an SSFP with a linear frequency response [4] is employed, which provides a nearly ideal homogeneous representation irrespectively of off-resonance effects. This allows for MT SSFP imaging over a broad range of TR without stringent requirements to the shimming procedure.

Methods

Experiments were conducted on a clinical 1.5T scanner (Achieva, Philips Healthcare) using a birdcage head coil. A cylindrical phantom filled with standard copper sulfate solution was used for the phantom study, and first *in vivo* experiments were performed in 3 healthy adults. A conventional SSFP sequence with OA (N=10 averages, TR/TE=3.2/1.6ms, α=55°, FOV=260×208×10mm³, measured resolution=1.0×1.0×10mm³) was compared with a novel approach based on a recently introduced "chimera" SSFP sequence [4]. It employs alternating repetition times ($TR1/TR2_{MT}$=3.2/4.8ms), partly unbalanced gradients, and has a linear frequency response. Therefore, a simple superposition of images acquired at different offset frequencies provides a near-ideal homogeneous signal intensity over a broad frequency offset range. A linear gradient (G=0.2mT/m) was applied in x direction to provoke banding artifacts and to evaluate the performance of the respective averaging approaches. Within the *in vivo* study, the chimera-based SSFP sequence was performed with the parameters shown above, and with a prolonged RF pulse (elongation factor=10) to decrease MT weighting, resulting in prolonged $TR1/TR2_{non\text{-}MT}$ = 6.0/9.0ms. No shimming was performed. A subtraction image was obtained to emphasize differences in the MT and non-MT weighted images.

Results and Discussion

The phantom results obtained with conventional SSFP in the presence of a linear gradient with and without OA are shown in Fig. 1 [a] and [b], respectively. The corresponding results obtained with chimera SSFP are shown in [d] and [e]. Intensity profiles across the phantom are shown in [c] and [f]. A residual "ripple" resulting from averaging of the nonlinear frequency response was observed with conventional SSFP averaging (solid arrow). A perfectly homogeneous representation was obtained using the linear combination of chimera SSFP. The *in vivo* results obtained with MT-Chimera SSFP (elongation factors 1 and 10) are shown in Fig 2 [a] and [b], respectively. The color-coded subtraction image is shown in [c]. No differences that could be attributed to susceptibility artifacts at prolonged TR were observed, and the different MT levels of gray matter, white matter, and CSF are clearly discriminated in the subtraction image.

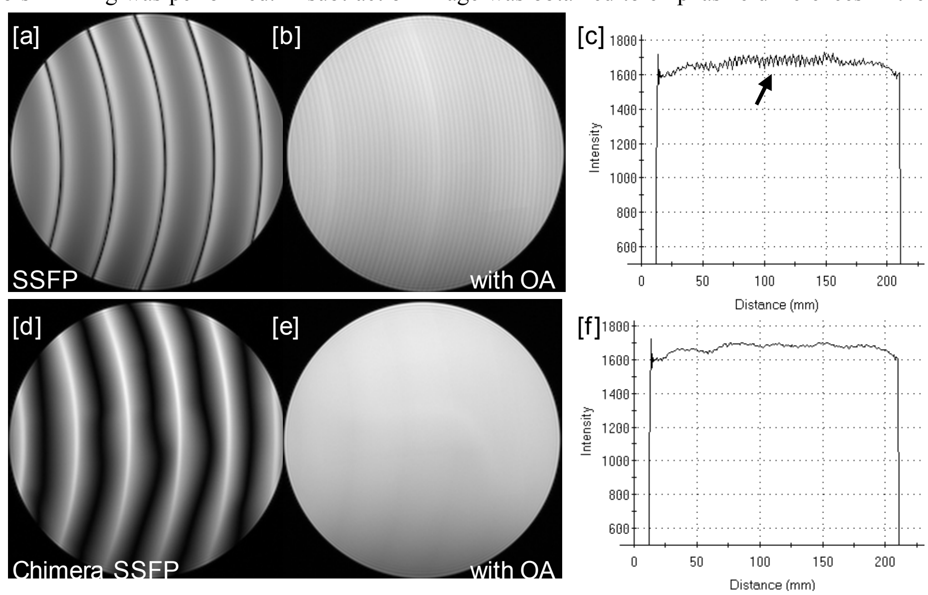

Fig. 1 Phantom images acquired with SSFP [a] and chimera SSFP [d] in the presence of a linear gradient. Offset averaging removes banding but yields a residual ripple in SSFP [b,c]. Near-ideal homogeneity is obtained with chimera SSFP using linear averaging [e,f].

Conclusion

Conventional SSFP with OA efficiently removes banding artifacts but reveals a residual ripple. This may not pose a problem to imaging; however, it may compromise the quantification of MT based on small changes in the signal intensity. We have successfully shown that chimera SSFP with linear averaging yields near-ideal homogeneity, and presents a robust means for MT SSFP imaging with prolonged TR. This approach may be appealing in anatomic regions where susceptibilities cannot be addressed by shimming alone.

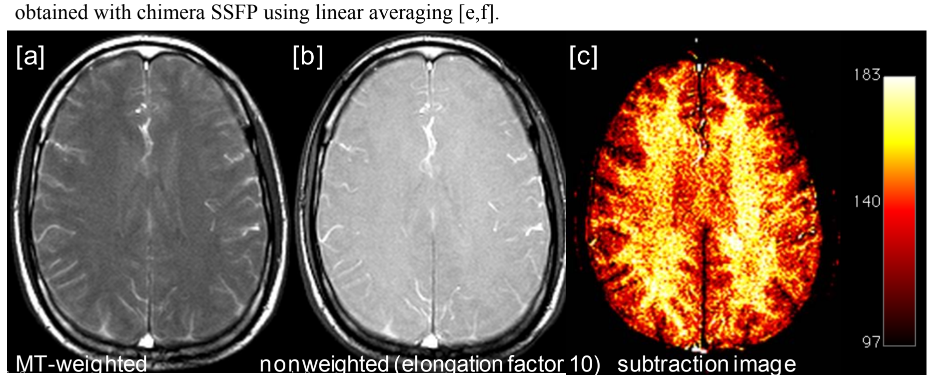

Fig. 2 In vivo results obtained with chimera SSFP and OA; MT-weighted image [a], nonweighted image with RF elongation factor 10 [b], and color-coded subtraction image [c]

References: [1] Bieri O et al, MRM (2006), [2] Gloor M et al, MRM (2008), [3] Bangerter NK et al, MRM (2007), [4] Bieri O et al, Proc. ISMRM 17, #2767 (2009)