Artifact-free and multi-contrast SSFP imaging achieved in a single acquisition

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Introduction

Balanced SSFP (bSSFP) is a pulse sequence with great clinical potential because of its short scan time, high SNR, and lower SAR (specific absorption rate). However, due to its sensitivity to field inhomogeneities, SSFP imaging is always degraded by the banding artifact [1]. Although the banding artifact may be reduced with improved shimming and shortened repetition time (TR), it cannot be completely avoided in critical regions near air-tissue boundaries. Recently, partially-dephased SSFP (PD-SSFP) was developed to reduce banding artifact by applying a small dephasing gradient during data acquisition, and then reconstructing images through extrapolation and peak detection [2]. However, the PD-SSFP image quality is still less than optimal due to the residual artifact. Here we report a novel reconstruction method to significantly improve PD-SSFP, enabling artifact-free, higher-SNR, and multi-contrast imaging in a single PD-SSFP acquisition.

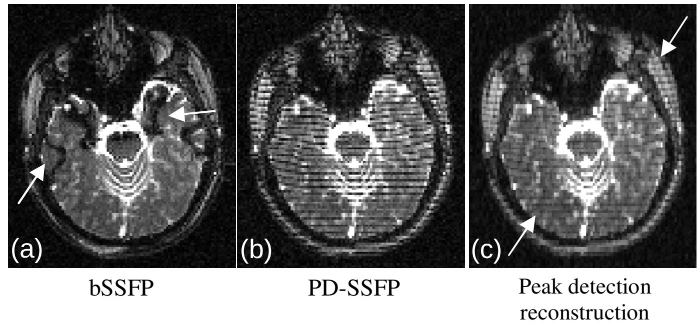

Figure 1 shows removal of banding artifact using the previously reported partially-dephased SSFP (PD-SSFP). (a) Banding artifact can be seen in bSSFP image at regions with strong susceptibility change (white arrows). (b) While banding artifact was alleviated in PD-SSFP, stripe pattern was induced by the partially-dephasing gradient. (c) The previously reported peak detection method can be used to reduce stripe in (b). However, residual artifact remains (white arrows).

Material and Methods

bSSFP and PD-SSFP data were acquired with a 3 Tesla GE system, with a partially-dephasing gradient applied along the readout direction of PD-SSFP (matrix 384x128, TR/TE = 6.3/3.15ms, flip angle 65^{o}). While the dephasing gradient results in stripe patterns in SSFP images (e.g. Figure 1b), it actually creates additional coherent pathways and thus separates k-space energy into multiple echoes. We, therefore, propose to decompose multiple echoes and reconstruct multiple images using the recently developed k-space energy spectrum analysis [3] and multi-scheme reconstruction methods [4]. Multiple reconstructed images, corresponding to different SSFP coherent pathways, actually have different T1 and T2 weightings. The multiple reconstructed images may be assessed separately, or combined to generate a single high-SNR, artifact-free SSFP image.

Results

Figure 1a shows conventional bSSFP image affected by the banding artifact (pointed by white arrows) at regions with strong susceptibility change. While the banding artifact may be lessened in PD-SSFP scan, the stripe pattern appears due to the repetitive signal modulation created by the applied dephasing gradient (Figure 1b). Using the previously reported peak detection method, the stripe pattern in PD-SSFP image may be reduced (Figure 1c). However, residual artifact remains (indicated by arrows). Figure 2 illustrates the novel post-processing method based on echo separation and multi-scheme reconstruction. Figure 2a shows that there actually exist three echoes in the k-space of a single PD-SSPF data set, originating from different coherent pathways. Using the multi-scheme reconstruction algorithm, these echoes were decomposed and placed in three different reconstruction windows (orange boxes). Figure 2b shows the composite image, generated by combining three echo images in the magnitude domain. Note that both banding and stripe artifacts were removed effectively using the novel echo separation and multi-scheme reconstruction. Figure 3 compares the conventional bSSFP image and multi-contrast PD-SSFP images obtained from the new reconstruction method. It can be seen that the conventional bSSFP image has a lower contrast between gray and white matter (Figure 3a). Figures 3b to d show images reconstructed from echo 1, 2, and 3 of PD-SSFP, respectively. Note that these echo image present different tissue contrasts, which can be used for tissue segmentation or parametric mapping. By summing those echo images, the generated composite PD-SSFP image (Figure 3e) provides improved gray-white-matter contrast, and higher SNR, in comparison to the conventional bSSFP data.

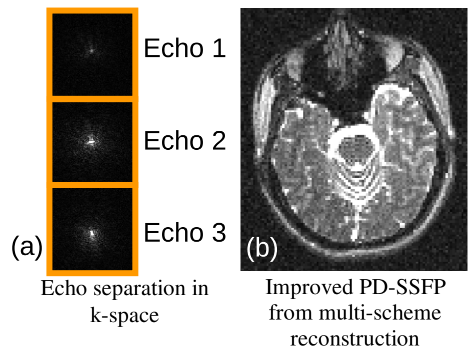

Figure 2 shows echo separation and multi-scheme reconstruction. (a) In k-space of 384x128, three echoes exist due to different coherent pathways of a single PD-SSFP scan. Three images can be generated using the multi-scheme reconstruction (orange boxes). (b) shows the composite image obtained by magnitude summation of three echo images. Note that both banding and stripe artifacts were effectively removed using the novel reconstruction method.

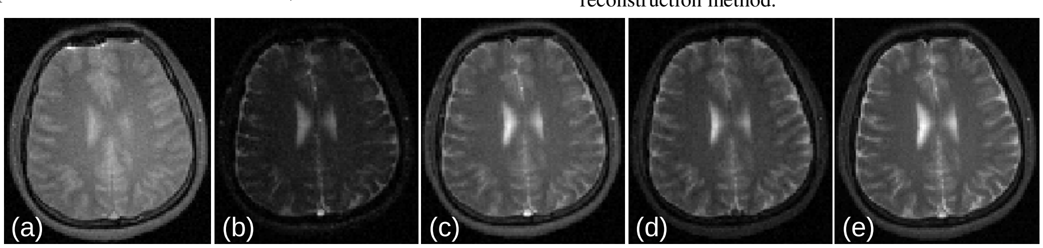

Figure 3 compares the conventional bSSFP image and multi-contrast images obtained from a single PD-SSFP scan. (a) The conventional bSSFP image shows lower contrast between gray matter and white matter. (b)-(d) are images reconstructed from echo 1, 2 and 3, respectively. Note that each echo image presents different tissue contrast. (e) The composite PD-SSFP image (i.e. magnitude summation of (b)-(d)) shows improved contrast and SNR.

Discussion

The proposed echo separation and multi-scheme reconstruction methods significantly improve the SSFP image quality. Artifact-free and high SNR SSFP images can be achieved with a single acquisition. Furthermore, data from multiple coherent pathways can be assessed separately, enabling multi-contrast imaging with a single acquisition. The multiple tissue contrasts, which are not available in previous methods, can be used for improving tissue segmentation and parametric mapping.

Reference

[1] Oppelt A., Electromedica 54: 15-18, 1986 [2] Hargreaves B. A., 16^{th} ISMRM, p. 1357, 2008 [3] Chen N. K., et al., NeuroImage 31: 609-22, 2006 [4] Chen N. K., et al., Magn Reson Med 59: 916-24, 2008