A NEW SYNTHESIS METHOD OF PHASE-CYCLED SSFP IMAGES TO REMOVE THE BAND ARTIFACT BY COMBINING COMPLEX SUMMATION AND MAXIMUM INTENSITY PROJECTION TECHNIQUES

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Introduction: The complex summation (CS) is known to be effective in reducing the band artifact as a synthesis method of multiple phase-cycled images (1). However, it was noted that CS is not reliable due to phase incoherence in the multiple phase-cycled images (2, 3). On the other hand, the maximum intensity projection (MIP) and spectral decomposition synthesis (SDS) techniques do not have the phase-related problem even though they might be less effective in reducing the band artifact. Here, the advantages of CS and MIP are combined as a more effective synthesis method (CSMIP) to take advantage of both techniques in reducing the band artifact without the detrimental effect of phase incoherence.

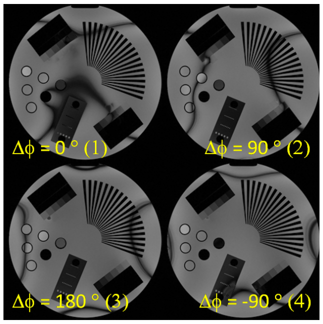

Fig. 1. Intensity images.

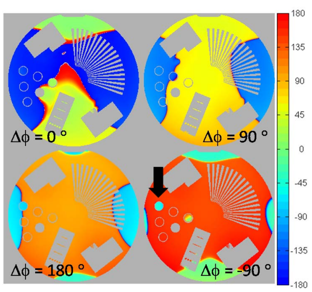

Fig. 2. Phase maps.

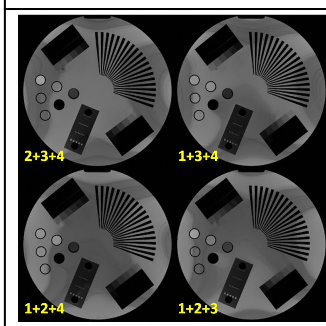

Fig. 3. Modular CS images.

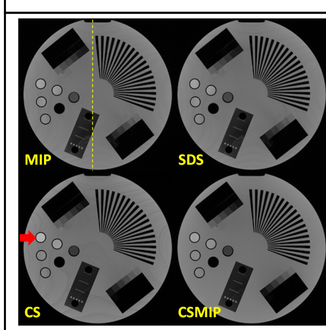

Fig. 4. Synthesized images.

Methods: Through a phantom experiment, it was noted that the phase incoherence in one image among the multiple phase-cycled images could result in an insufficient reduction of the band artifact and even abnormal image intensity. Since the stop bands do not overlap among the multiple phase-cycled images for the area with mild susceptibility, only a subset of the multiple phase-cycled images could be enough to reduce the band artifact through CS. A summation of the subset images excluding the image with the phase incoherence at a local area could avoid the phase-related problem even though the band artifact may not be reduced over the whole image. When four phase-cycled images are acquired, each subset can consist of three images and thereby four modular CS images can be constructed. The modular CS images can be synthesized by using MIP to reduce the band artifact over the whole image. A phantom was scanned at 3T with a TrueFISP sequence for 4 phase-cycling schemes of $\Delta\phi$ = 0°, 90°, 180° and -90° (flip angle = 70°, TR = 5.6 ms, TE = 2.8 ms, transverse orientation). To induce a field inhomogeneity, a x^2y^2 shim term was intentionally shifted from the auto shim result by about -14%. The phase map was obtained from the TrueFISP images after low-pass filtering. Four modular CS images were constructed and combined together by MIP. In addition, SDS was constructed with a Gaussian window of σ = 1 to be compared with this new technique. The image intensity of synthesized results was normalized to MIP for the large container solution to help a direct comparison. The band artifact and image noise in the synthesized results were analyzed by measuring the standard deviation in the ROI of the phantom and background, respectively. CSMIP was also applied for a subset consisted of 2 images instead of 3 images. In addition, the powered averaging of the modular CS images such as the square-of-sum was compared with MIP.

Results: In each SSFP image the dark band (**Fig. 1**) was along the phase transition in the phase map (**Fig. 2**) without spatial overlapping among the phase-cycled images. Each of the four modular CS images still had the dark bands which were widened up from the narrow band (**Fig. 3**). The MIP result of the modular CS images was almost free of band artifact (**Fig. 4**). The profiles through a column (marked in MIP of Fig. 4) were plotted in **Fig. 5** for the four modular CS images and CSMIP**.** The fluctuating profiles in the modular CS images were flattened in CSMIP. The synthesized profile of CSMIP was compared with MIP and CS (**Fig. 6**) where abrupt peaks represented the remaining band artifact in both MIP and CS. CSMIP was best in reducing both the band artifact and image noise (**Table 1**). CS was worst in reducing the band artifact and SDS performed reasonably well, close to CSMIP for both band artifact and noise reduction. It was also noted that CS resulted in an elevated intensity of a small tube (marked by a red arrow in Fig. 4) that contained Gd-doped water (**Table 1**), which might be induced by the phase shift of the tube as shown in Fig. 2 (marked by a black arrow). The subset consisted of 2 images was less effective in reducing the band artifact than the subset of 3 images. The powered averaging was worse than MIP because it inherited the property of the magnitude averaging technique. In conclusion, the new technique, CSMIP, was very effective in reducing both the band artifact and image noise without the phase-related problem in the complex summation.

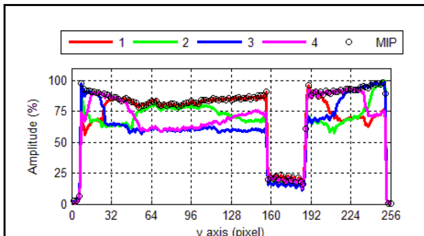

Fig. 5. Profiles of the modular CS images and the MIP image.

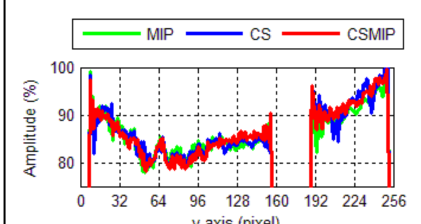

Fig. 6. Profiles of synthesized images.

Table 1. Standard deviation and mean (tube) from ROIs in reference to MIP (%).

Synth-esis	Phantom	Back-ground	Tube
MIP	100.0	100.0	100.0
SDS	97.9	88.3	100.4
CS	115.7	97.8	111.8
CSMIP	94.5	85.3	100.1

References: 1. Vasanawala SS, Pauly JM, Nishimura DG. Magn Reson Med 2000;43(1):82-90. 2. Cukur T, Bangerter NK, Nishimura DG. Magn Reson Med 2007;58(6):1216-1223.
3. Jung K-J. ISMRM 2008; Toronto, Canada. p 1361.