PITFALLS OF COMPLEX SUMMATION AND ITS VARIANT METHOD IN SYNTHESIZING THE PHASE-CYCLED SSFP IMAGES TO SUPPRESS THE BAND ARTIFACT

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Introduction: The SSFP image suffers from a band artifact. The complex summation (CS) method has been reported to be better than the maximum intensity projection (MIP) in suppressing the band artifact (1). However, it was noted recently that CS has an inherent deficiency in suppressing the band artifact due to phase incoherence across the phase-cycled images (2,3). It was stated that a magnitude-weighted CS method (MWCS) was more reliable than CS and SoS (square-of-sum) in suppressing the band artifact (2). In this abstract, the pitfalls of CS and its variant MWCS are examined with an experimental demonstration and a computer simulation.

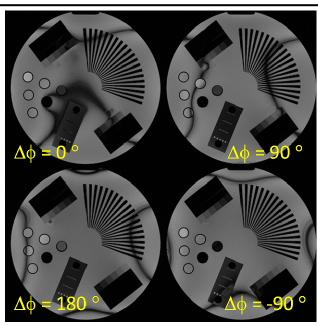

Fig. 1. Intensity images.

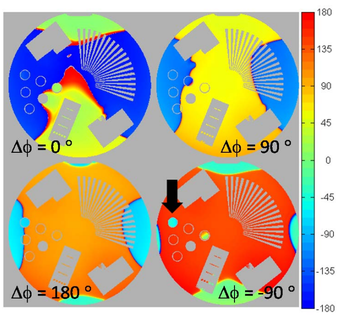

Fig. 2. Phase maps.

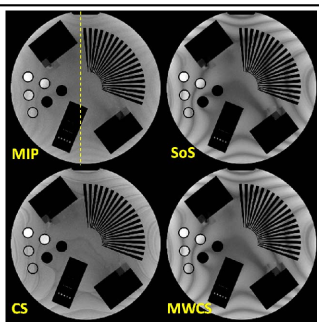

Fig. 3. Synthesized images.

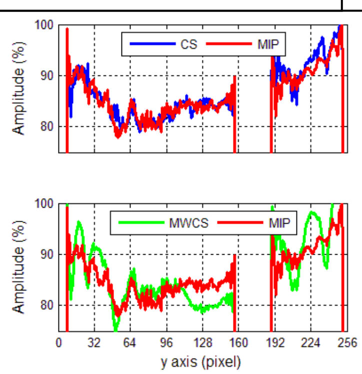

Fig. 4. Profiles of synthesized images.

Methods: 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 removing the background phase by low-pass filtering. The synthesis methods of MIP, SoS, CS, and MWCS were compared for the phantom images as well as for simulation with relaxation times of the phantom solution (T1 and T2 = 274 and 155 ms). The image intensity of the synthesized images was normalized to that of MIP for the large container solution to help a direct comparison among the synthesis methods.

Results: The position of the dark band artifact in the magnitude image (**Fig. 1**) was along the phase transition in the phase map (**Fig. 2**) as expected. None of the tested synthesis methods could fully suppress the band artifacts (**Fig. 3)**. The image profiles along the vertical line (shown in MIP in Fig. 3) demonstrated the higher remaining band artifact of CS and MWCS in comparison with MIP (**Fig. 4**). It was clear that CS was better than MWCS, which is opposite to the claim in ref. 2. One surprising abnormality was the small tube filled with Gd-doped water (**Fig. 5**, a red arrow). The T1 and T2 of the tube were measured as 27 and 26 ms, respectively. Notably, the image intensity of the tube was increased by 12% in CS compared to MIP, as shown in the subtraction image in Fig. 5. This tube showed a clear phase shift on the phase map (in particular at $\Delta\phi = -90°$, marked by a black arrow). The computer simulation compared the ripple factor (= (maximum – minimum)/mean x 100%) of each synthesis method (**Fig. 6**). At the flip angle of 70° used in the experiment, MIP was observed to suppress the band artifact better than CS and MWCS even though MWCS could be better than others at around 55° of the flip angle.

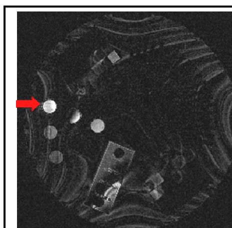

Fig. 5. A subtraction of MIP from CS.

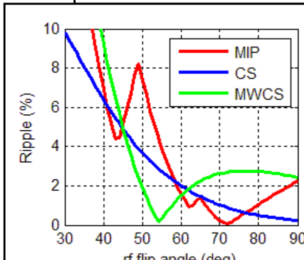

Fig. 6. Ripple factor of the three synthesis methods.

Discussions: The band artifact suppression of each synthesis method depends on the relaxation time and flip angle. The CS and its variant method such as MWCS can produce abnormal image intensity due to a local phase shift. Even though MIP does not take advantage of the signal-to-noise ratio (SNR) improvement, it may be more reliable than CS and its variant method. In this aspect, the spectral decomposition synthesis (SDS) method (3) might be useful since it is based on MIP but it can provide an improved SNR by taking advantage of averaging the multiple phase-cycled images. The MWCS could inherit the problem of phase and amplitude modulation from CS and the magnitude averaging method, respectively. The adjustment of power for MWCS could reduce the problem of magnitude modulation, but it would not eliminate the magnitude modulation effect. The band artifact is contributed not only from the dark band but also from the high signal or bright band. The bright band occurs around the stop band at a lower flip angle for certain relaxation times as often found in eyeballs. The bright band will be pronounced in MIP and its variant, while it could be better suppressed in CS and its variant. On the other hand, the balanced SSFP sequence usually sacrifices the slice profile to shorten the rf pulse duration. This short rf pulse will have more and higher sidebands of the slice profile, and thereby more complicated slice signal profile due to a nonlinear response of the SSFP signal to the rf flip angle and relaxation times.

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.