Slice Dispersed Linear Combination SSFP - a new tool for Banding Reduction

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Introduction: The linear-combination (LC)SSFP technique has been successfully employed to reduce banding in SSFP images[1]. However, as will be illustrated below, a non-trivial amount of ripple from these bands can remain. This abstract outlines a new modification to the LCSSFP sequence that will significantly reduce this residual banding.

Theory: The steady-state response to a balanced-SSFP sequence is periodic with respect to frequency[1], as is depicted in Figure 1a below. This generates the ubiquitous bands seen in balanced-SSFP images (Figure 1b). Our slice-dispersed modification applies a time-invariant gradient in the slice-select direction to create a frequency spread across the slice. The strength of this gradient is defined by $\frac{1}{\gamma \cdot \Delta s \cdot TR}$, where Δs is the slice thickness. The frequency spread across the slice is equal to $1/(2 \cdot TR)$, the same as the frequency width of one banding structure. If the steady-state response did not alternate in phase between successive bands, this modification alone would cause the banding pattern across the slice to average out to the same value over all pixels, and one could obtain completely uniform images with a single average with no loss in SNR. Unfortunately, in places where the slice straddles two successive bands, the signal from different phases cancels out, resulting in signal loss, and an overall pattern resembling a sawtooth is formed (Figure 1c). Fortunately, if one performs linear combination phase cycles in multiples of 2, the peaks and valleys of the different sawtooth patterns will fit into each other, generating a total profile that is roughly uniform.

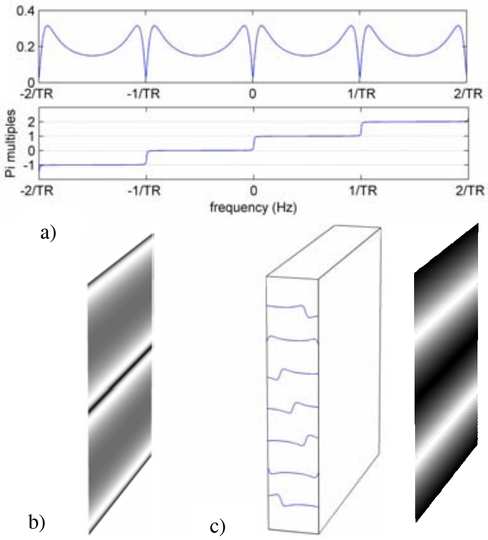

Figure 1. a) SSFP frequency response. b) Normal banding profile. c) New banding profile after dispersion of frequency across slice.

Materials and Methods: Images were acquired using a balanced-SSFP sequence on a 3 Tesla MRI unit (Philips Intera System). A TE/TR of 5.5/11 ms was used, together with a slice thickness of 5 mm and a flip angle of 18 degrees. Following the LCSSFP technique, each average was implemented with a different phase cycling interval, defined by 2πn/N, where n refers to the nth average, and N represents the total number of averages. The transmit phase of the rf pulse is incremented by this amount each TR. Acquisitions with both 2 and 4 averages were implemented. This same imaging protocol was then repeated with a constant gradient superimposed in the slice-select direction, at a strength of 0.427 mT/m according to the expression above. The method was verified first on a phantom, and then on in-vivo brain. The phantom was a 10 cm water-based sphere with the X shim mis-set. Our scanner combined the averages using the root sum-of-squares method.

Results and Discussion: The phantom and brain images are shown in Figures 2 and 3, both with and without our gradient modification. There is an obvious reduction in banding appearance between the traditional LCSSFP and our slice-dispersed version. Even the 2-average slice-dispersed LCSSFP appears to be more uniform than the 4-average traditional implementation. Of course, this comes at a cost of SNR. For any single average, the total image SNR will drop by 50 percent when employing the slice-dispersed modification. However, in cases where image SNR is not limited, and/or where banding is complicating the appearance of anatomy, this method would allow for a much more uniform image appearance, perhaps even with the application of fewer averages and a reduction of scan time.

In future work, a rigorous comparison of the banding response between traditional LCSSFP and our slice-dispersed version will be performed using frequency profile simulations over a complete range of imaging T1 and T2 relaxation times. These comparisons will investigate a variety of linear combination techniques including root sum-of-squares, complex summation, and magnitude summation.

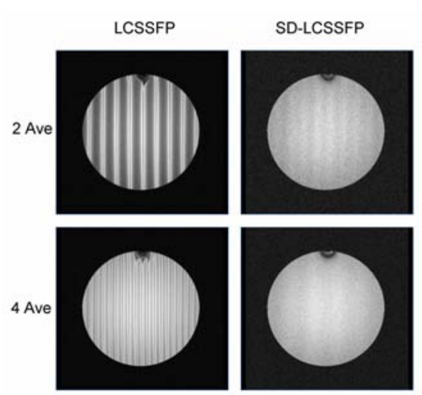

Figure 2. Phantom Images

Conclusions: Preliminary investigations of the slice-dispersed LCSSFP method hold promise to be very effective at reducing the banding artifacts that affect balanced-SSFP images. Provided signal levels are sufficient, the potential exits for improved image appearance with shorter scan times. This reduction in banding appearance may also relax limitations on the TR, which is typically set as short as possible to reduce banding incidence.

References
1. Bangerter, N.K. et. al. MRM, 51:1038-1047, 2004

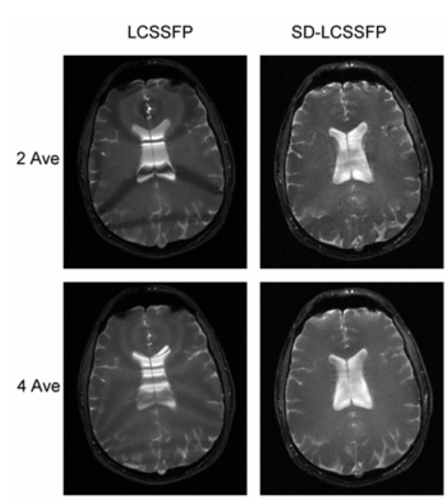

Figure 3. Brain Images