Shim Cycling Technique to eliminate the banding artifacts in 3D bSSFP Inner Ear Images

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Introduction Balanced SSFP (bSSFP) pulse sequences such as TureFISP or FIESTA allow the rapid acquisition of images with a high SNR, with relative immunity to flow artifacts and good contrast between the CSF and other structures such as nerves and bone. With a very short TR and complete balancing of the gradients in all 3 directions, bSSFP has been used recently for the visualization of inner ear structures, at the resolution desired for many inner ear pathologies[1-3]. However, the large susceptibility-induced variations in B0 result in banding artifacts in bSSFP images. These bands, which occur at a spacing of 1/TR in terms of the local B0 Larmor frequency, become more closely spaced due to the longer TR required for very high resolution imaging of the inner ear. This banding problem has been eliminated in many cases by techniques, such as the CISS sequence[4], which acquire a number of bSSFP data sets, each with a distinct radiofrequency (RF) phase cycle increment. This phase cycling spatially shifts band artifacts on each image set. When the susceptibility variation is too large, the band may not shift enough to be eliminated by phase cycling. Because of the complicated structure of the inner ear, it is not possible to completely correct the local magnetic field homogeneity around the inner ear. One possible solution is to acquire multiple image volumes with shim values adjusted to shift the banding artifact. A similar technique used increments in the z-gradient refocusing pulse to "shim" away the susceptibility artifact in EPI images [5-6]. In this work, we present a shim cycling technique to eliminate the banding artifacts in 3D bSSFP inner ear images in which multiple image sets are acquired with different shim currents during the acquisition of each set to change the local field compensation.

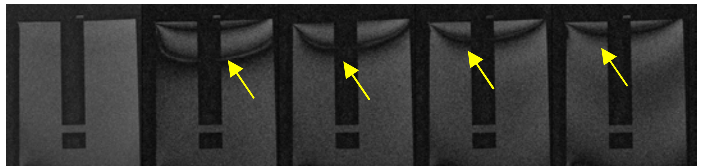

Fig. 1: (Left) Composite phantom image averaged from seven shim steps and (Right) four individual shim cycling images of the same slice location.

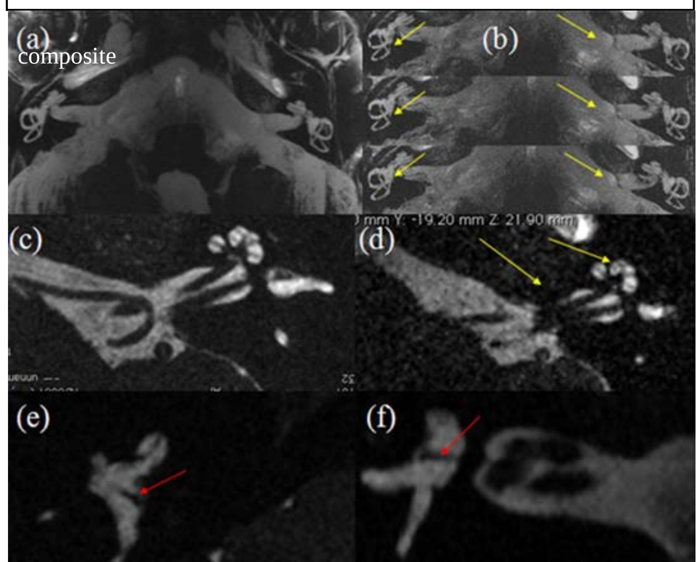

Fig.2: MIP images constructed from composite images of the entire volume (a) and three individual shim cycling volumes (b). Axial MPR views created from composite (c) and routine (d) volumes. Oblique coronal (e) and coronal (f) view images of the Utricular Macula obtained from composite MPR.

Methods: All MRI scans were performed on a Siemens 3Tesla TIM Trio scanner. **Phantom scans:** A cylindrical phantom filled with a 0.1 mM $MnCl_2$ solution was scanned with a 12 channel head coil. A large air bubble at the top of the phantom was used to create the field variation. Seven sets of 3D TrueFISP images were acquired with the following parameters: coronal plane, TE/TR=3.1/6.3 ms, 0.4 isotropic voxel size. After the initial adjustment of the volume shims, Tx voltage, and center frequency, seven 3D Trufi (TrueFISP) image volumes were acquired. Between each volume acquisition the z-shim was altered, so that successive sets of images have different amounts of z-shim. The **Human study:** In a similar experiment, a human volunteer was scanned with a custom built 4 channel (2 channels bilateral) ear coil. 3D Trufi image of the inner ear were acquired with the x-shim stepped between each acquisition. 3D TrueFISP parameters were: TE/TR=3.4/6.8 ms, FA=50^o, FOV=160x160 mm^2, matrix=384x384x48. The total scan time was 14 minutes. Acquisition voxel dimension was 0.4 mm isotropic and displayed as 0.2 mm isotropic after zero-filled interpolation. Again, the shim step was chosen to move the bands by a few pixels. To create the composite volume a median filter was applied along the shim steps with a width equal to the number of shim cycling volume.

Results: Fig.1 shows the results from the shim cycling phantom study. The composite image (left image) demonstrates the elimination of the banding artifacts which are clearly seen in the four individual shim cycling images (yellow arrows). Fig. 2 displays the maximum intensity projection (MIP) images reconstructed from composite volume images (a) and from three individual volumes each with a different x-shim step (b). The MIP of the composite volume displays the entire inner ear anatomy with no apparent banding compared to MIPs of the individual volumes, which show considerable banding (yellow arrows in b). The axial view of the composite image (c) can identify the facial nerves, and superior branch of the vestibular nerve where the banding artifact is severe in routine image (d). Oblique coronal (e) and coronal (f) views reformatted from the composite volume images can clearly display the Utricular Macula (red arrows).

Discussion: These preliminary results give a strong indication that shim adjustments can sufficiently shift the banding artifact in 3D Trufi images that very uniform composite images can be obtained. Although this was performed using 0.4 mm isotropic resolution, it would appear that banding artifacts in higher resolution images, with even longer TR, could be corrected. This work will be important for very high-resolution 3D TrueFISP imaging of the inner ear.

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