Artifact Correction in Temporal Bone Imaging with GS-bSSFP

Michael N Hoff[1], Greg J Wilson[1], Qing-San Xiang[2,3], and Jalal B Andre[1]
[1]*Department of Radiology, University of Washington, Seattle, WA, United States,* [2]*Department of Radiology, University of British Columbia, Vancouver, BC, Canada,* [3]*Department of Physics, University of British Columbia, Vancouver, BC, Canada*

Introduction Imaging the temporal bone is important in the diagnosis of many pathologies, including congenital ear anomalies, vestibular schwannoma, semicircular canal dehiscence, and inner/middle ear lesions[1]. High resolution balanced steady state free precession (bSSFP) imaging is ideal for visualizing the inner ear's fine structure, since its high tissue/fluid contrast can easily diffentiate the inner ear's endolymph and perilymph from surrounding tissue. Unfortunately, images suffer from motion artifacts due to arterial and CSF flow, and bSSFP signal modulation due to interpulse phase accumulation θ caused by off-resonance phenomena common near the sinuses. This signal modulation can yield dark image bands if off-resonance frequencies exceed ±1/(2TR).

Although short TR and powerful gradients can reduce banding, field inhomogeneity and SAR and TR limitations often make image bands unavoidable. Typically, variably phase cycled images with spatially shifted bands are combined to achieve band reduction[2,3]. Previous work demonstrated that a geometric solution (GS) of four such phase cycled images computes a θ-independent bSSFP magnetization[4]. Here we show that when applied clinically to imaging of the temporal bone and foramen magnum, the GS is not only able to eliminate signal modulation and banding in bSSFP images, it also reduces motion artifacts relative to a complex sum (CS) of the phase cycled images.

Methods A Philips Ingenia 3T magnet with a transmit/receive head coil was employed to acquire four 3D axial bSSFP images with Δθ = 0°, 90°, 180°, and 270° phase cycling respectively (Fig. 1). Scan parameters were α = 30°, TE/TR = 4.2/2.1ms, receiver bandwidth = 890 Hz/pixel, and 180/180/120 matrix size and 1/1/1 mm voxel size along frequency/phase/slice directions.

The real components x_j and imaginary components y_j of the j = 1,2,3, and 4 complex images I_j were input into Eq.(1) for calculation of the demodulated GS on a pixel-by-pixel basis. This is analgous to plotting all four image pixels in the complex plane, and finding the cross-point of the alternating phase cycles. SNR was improved through a second pass solution as previously described[4,5].

$$\mathbf{GS} = \frac{(\mathbf{x_1 y_3} - \mathbf{x_3 y_1})(\mathbf{I_2} - \mathbf{I_4}) - (\mathbf{x_2 y_4} - \mathbf{x_4 y_2})(\mathbf{I_1} - \mathbf{I_3})}{(\mathbf{x_1} - \mathbf{x_3})(\mathbf{y_2} - \mathbf{y_4}) - (\mathbf{x_2} - \mathbf{x_4})(\mathbf{y_1} - \mathbf{y_3})} \qquad (1)$$

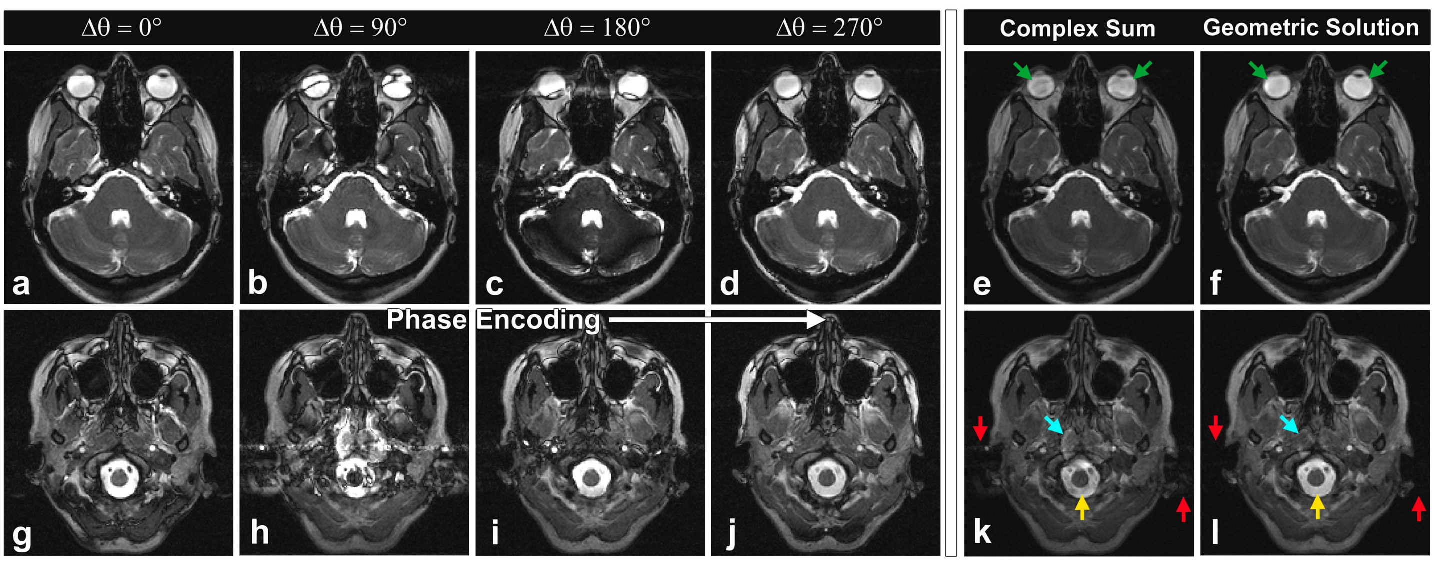

Fig. 1: Demodulation of bSSFP brain images. bSSFP axial magnitude images of the inner ear (above) and foramen magnum (below) phase cycled by Δθ = a) & g) 0°, b) & h) 90°, c) & i) 180°, and d) & j) 270° respectively are shown. The Complex Sum of each set of phase cycles given in e) & k) has colored arrows indicating residual banding in the CSF (yellow) and globes (green), signal modulation in the prevertebral space (blue), and motion artifact (red). Arrows of equivalent colors in the Geometric Solution images of f) & l) demonstrate near elimination of all artifacts.

Results Fig.1 depicts the four phase cycled Δθ = 0°, 90°, 180°, and 270° axial magnitude images of the temporal bone and foramen magnum, and the corresponding CS and GS solutions. The original phase cycled bSSFP images demonstrate banding, spuriously bright signal regions, and periodic motion artifact along the phase encoding direction stemming from globe motion, CSF pulsation, and carotid arterial flow. Colored arrows in the CS show residual banding in the globes (green) and CSF (yellow), erroneous contrast in the nasopharynx and prevertebral space (blue), and residual vascular and CSF flow artifact (red). Equivalently colored arrows in the GS indicate that nearly all artifacts are eliminated relative to the CS.

Discussion The geometric solution to bSSFP signal demodulation is clinically applied to imaging of the temporal bone and adjacent structures. The technique required only 2.3 minutes for the four 120-slice bSSFP datasets, and was easily implemented via complex data export from the standard "bFFE offset averaging" protocol. Post-processing is minimal since the solution is analytical in nature. The GS demodulates bSSFP signal of its off-resonance dependence; unlike the CS, it yields reliable contrast without banding. The GS also achieves high noise immunity, as exemplified by its insensitivity to motion artifacts in the original phase cycled images. Further testing is necessary for a complete understanding of the GS' reliability in the presence of flow and motion.

References: 1. Mohan S *et al.*, MRIClinics, 20:545-572, 2012. 2. Zur Y *et al.*, MRM, 16:444-459, 1990. 3. Casselman JW *et al.*, AJNR, 14:47-57, 1993. 4. Xiang QS & Hoff MN, Proc. ISMRM, 18:74, 2010. 5. Xiang QS & An L, JMRI, 7:1002-1015, 1997.