Spinal Cord Imaging with Demodulated bSSFP

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Introduction Balanced Steady State Free Precession (bSSFP) imaging has the potential to improve the detection and evaluation of spine and spinal cord pathologies**,** and is an ideal candidate for deliniation of lesions within the intradural, extramedullary space. This in part due to its high cerebrospinal fluid (CSF) signal that facilitates visualization of edges of the spinal cord and epidural structures. This quality also make it useful for high-resolution myelographic imaging of the spine[1,2]. The difficulty in employing bSSFP imaging of the spine lies in bSSFP's sensitivity to off-resonance, a phenomenon exacerbated at higher magnetic fields. Accumulation of off-resonance phase gives rise to dark image bands that may easily be confused with cord edges or other pathology.

Most clinical bSSFP protocols are designed to obviate the occurrence of bands by minimizing the time TR during which off-resonance phase can accumulate. However, residual banding often still degrades images. The second option is to phase cycle the RF pulse or equivalently offset the center frequency of the examination, such that bands are spatially shifted away from the region of interest. This method is arbitrary and prone to errors, and does not represent a robust solution to the problem. Recently it was discovered that a geometric solution (GS) using four variably phase cycled images computes signal independent of off-resonance modulation[3]. Here a clinical application of this technique to cervical spine imaging is demonstrated, with the GS eliminating banding and generating even signal in the CSF such that the myelographic contrast is more accurately visualized. These results are compared with an alternative method which combines the phase cycled images via a complex sum (CS)[4].

Methods A Philips Ingenia 3T magnet was employed to acquire four sagittal 3D bSSFP images with $\Delta\theta = 0°$, 90°, 180°, and 270° phase cycling respectively (Fig. 1) using its body coil. Scan parameters were $\alpha = 30°$, TE/TR = 4.4/2.2ms, receiver bandwidth = 885 Hz/pixel, and 200/200/45 matrix size and 1/1/3 mm voxel size along frequency/phase/slice directions.

The GS was computed on a pixel-by-pixel basis using a simple formula which 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[3,5].

Results Fig.1 depicts the four phase cycled $\Delta\theta$ = 0°, 90°, 180°, and 270° sagittal magnitude images of a cervical spine examination, and the CS and GS of the corresponding original phase cycled complex images. The phase cycled bSSFP magnitude images display banding and uneven signal intensity which is not representative of the tissue. The CS reduces banding considerably, but has uneven CSF signal intensity. The GS removes bands entirely, and yields even CSF signal intensity such that the extent of the edges of the spinal cord and epidural space are easier to visualize.

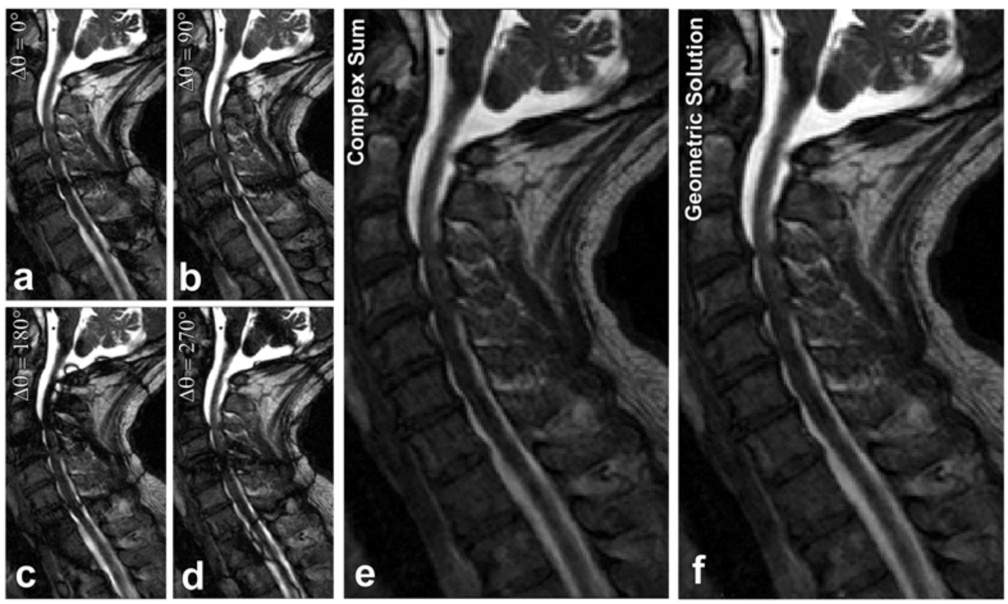

Fig. 1: Demodulation of bSSFP spinal cord images. bSSFP sagittal magnitude images of the cervical spine phase cycled by $\Delta\theta$ = a) 0°, b) 90°, c) 180°, and d) 270°. The Complex Sum image of the complex data contributing to a) – d) is displayed in e), demonstrating some debanding but slightly variable CSF signal. The Geometric Solution image given in f) eliminates banding and yields more homogeneous CSF signal.

Discussion The limitations of imaging the spine and spinal cord with bSSFP are shown to be eliminated when the GS is used for signal demodulation. The sequence can be performed in 2 minutes, is easily implemented through a complex data export from the standard "bFFE offset averaging" protocol, and requires minimal post-processing time. The GS eliminates the off-resonance dependence of bSSFP imaging; it removes bands in the CSF in a manner similar to the CS, but additionally yields more homogeneous and brighter CSF signal. This results in trustworthy myelographic images of the spine, without artifactual narrowing of the spinal canal as might be indicated by the CS. The technique was also insensitive to CSF flow, and thus represents a robust method for myelographic spinal imaging.

References:

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