Gross structure of magnetic field inhomogeneity in the human cervical spinal cord

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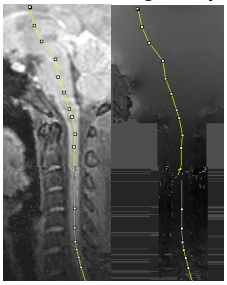
Target Audience: spinal cord imaging researchers

Purpose: The magnetic field (B0) inhomogeneity in the spinal cord is an acknowledged,[1] but little investigated, obstacle to MRI of this region. Kim et al.[2] have reported respiration-correlated B0 fluctuations in the spinal cord that decrease with distance from the lungs; Lim et al.[3] have demonstrated the feasibility of using frequency selective imaging to investigate B0 across the spinal cross-section, and Lundell and Cohen-Adad [4] have used point-spread function maps to improve spinal DTI, but a cohesive view is lacking. We report here our observations on the variations in B0 along the length of the human cervical spinal cord.

Methods: Six volunteers were scanned on a 3T scanner (Achieva, Philips Medical Systems, Best, The Netherlands). Time-averaged and time-resolved sagittal 3D phase mapping was used, covering from T1 to mid-brain with an 8 channel head and neck coil. Imaging parameters for the Time-Averaged sequence were: TE/TR 4.6, 6.9/ 10.0 ms, flip angle 10°, matrix 200x200x144 reconstructed to 800x800x144 at 0.38x0.38x1.5 mm; and for the Time-Resolved sequence: TE/TR 2.3, 4.6 / 5.83 ms, flip angle 10°, matrix 92x91x7 reconstructed to 176x176x7 at 1.4x1.4x3.0 mm, 30 dynamics, 470 ms/dynamic, both with slice and readout flow compensation. B0 profiles were extracted along a 3 voxel-wide curve that followed the longitudinal axis of the spinal cord, the brainstem and extended up to the corpus callosum (Fig. 1).

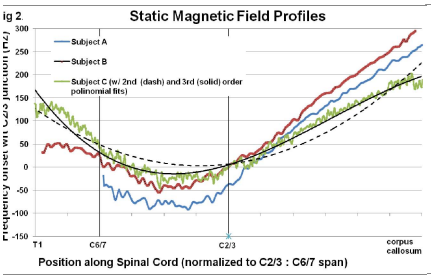
Results: Between the brain and mid-cervical spine, B0 differed by 200 – 350Hz, with partial recovery in lower cervical spine (Fig. 2). The average (±stdev across subjects) maximum absolute residual inhomogeneity after polynomial fitting was 40 (±15)Hz and 10 (±4) Hz for 2nd and 3rd order fitting respectively. Within the cervical spine, step-like B0 variations (~ ± 3-5Hz) having a scale similar to that of the vertebral body lengths were apparent in the temporal averages of the Time-Resolved profiles (Fig. 3), superposed on the shoulder-to-brain inhomogeneity. The standard deviation of the Time-Resolved profiles varied little over the length of the cervical spine (Fig. 3).

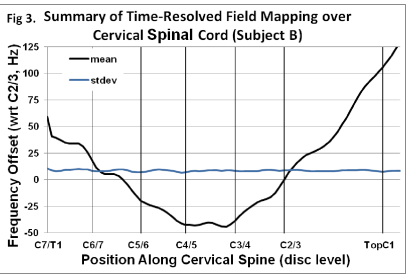


Left: Fig. 1. a) Tissue image and b) field map showing course of sampling.

Right: Fig. 2 Comparison of magnetic field profiles from shoulder to corpus callosum in 3 subjects with overlay of 2nd and 3rd order polynomial fits for Subject B.

Far Right: Fig. 3. Temporal standard deviation (blue) of B0 showed little variation over length of cervical spine. Mean B0 shows variation at the scale of vertebral bodies superposed on the primary inhomogeneity.





Discussion: The B0 difference between brain and mid-cervical spine is similar to that typically reported for across the orbito-frontal cortex.[5] As the length involved is greater, the effects should be lesser in the spine. The third or higher order terms required to describe the inhomogeneity may in part explain the difficulties experienced in shimming the cervical spinal cord for imaging as most scanners provide control only to 2nd order. Over the length of the cervical spine, the use of lower order shims could lead to a 5Hz or greater variations over lengths of 5mm, with associated implications for signal loss through T2* shortening. Over shorter distances, lower order shimming may suffice, but shim control per slice would be better able to also compensate for the smaller oscillations of 3-5Hz that were observed over intervals roughly corresponding to the vertebral body heights.

Most prior reports have focussed on the vertebral bodies and discs as a source of these smaller scale inhomogeneities along the spinal cord; however, spinal processes and associated muscles are also likely sources of static B0 inhomogeneity.

The lack of a significant increase in temporal variability in B0 nearer the lungs is in contrast with the results of Kim et al.[2] and with studies showing greater respiration-correlated EPI signal fluctuations in the spinal cord relative to the brain (e.g. [6]). We are examining the possibility that the echo separation was too short to be sensitive to these variations at the SNR of our current images. Also to be verified is the possible role of coil sensitivity in the observed large scale B0 inhomogeneity.

Conclusion: In these preliminary results we have demonstrated both large and small-scale structure in B0 of the human spinal cord, forming a first step in appropriately tailoring solutions for in-vivo imaging.

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