# Slice-Dynamic Shimming for Simultaneous Brain and Spinal Cord fMRI

Christine Law[1], Haisam Islam[1], Gary Glover[1], and Sean Mackey[1]
[1]*Stanford University, Stanford, CA, United States*

**Target Audience:** Neuroscientists interested in simultaneous brain and spinal cord fMRI; physicists challenged by brain and spinal cord imaging.

**Purpose:** To develop a slice-based shimming technique for simultaneous brain and spinal cord fMRI. Important functions of the central nervous system, such as pain processing and motor execution, engage the spinal cord [1]. But simultaneous brain/spine fMRI has not been adopted due to the challenge of shimming multiple regions having high magnetic field inhomogeneity. A dynamic shim update technique was recently proposed, to address this issue, that used separate linear gradients for brain and spinal cord [2]. We propose a technique to advance this concept by applying optimal linear shim values on a per-slice basis. Our slice-based technique, which calculates optimal shimming from a field map, would not be possible using the shim procedure provided by a scanner manufacturer as in [2].

**Methods:** A field map of $N_b = 20$ brain slices and $N_n = 5$ spinal slices was acquired with a GRASS sequence at two echo times ($\Delta TE = 0.5$ ms) on a 3T GE Discovery MR750 scanner using a HDNV coil. To minimize field inhomogeneity with a per-slice dynamic shim where the linear gradients and frequency offsets can be updated, we obtain the least-squares solution to $\gamma Ec = -b$, where scalar $\gamma$ is the gyromagnetic ratio, $b$ is the off-resonance, $c$ is the current for each coil, and $E$ is the spatial encoding matrix. The columns of $E$ include one set of second-order gradients $xy$, $x^2 - y^2$, and $z^2 - (x^2 + y^2)/2$, and, for each slice, a set of linear gradients $x$ and $y$, and a frequency offset. For each slice-specific column, entries for voxels in other slices are set to zero. The gradients $xz$, $yz$, and $z$ are not included because, for a given slice, they are redundant with $x$, $y$, and the frequency offset, respectively. Only voxels inside a mask, obtained from a magnitude image, are included in the least-squares calculation.

**Results:** Figures 1 and 2 show the magnitude images and field maps (after single shimming of the entire brain and spinal cord) from the GRASS sequence respectively. Using the same idea as in Ref 2, two sets of linear shim currents and frequency offsets (one for brain and one for spine) were calculated (also including the terms $xz$, $yz$, and $z$). Field maps simulated using these values are shown in Fig.3. Figure 4 shows simulated results using the proposed slice-based dynamic shimming technique.

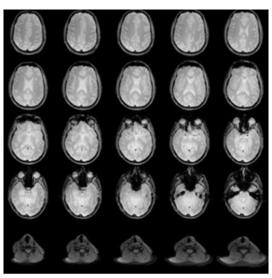

**Fig.1:** Magnitude images

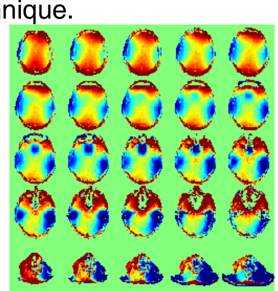

**Fig.2:** $B_0$ map after single shimming of brain and spine

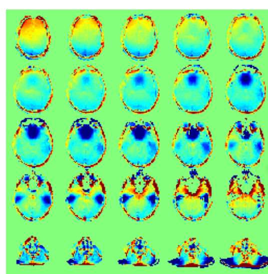

**Fig.3:** Separate shim for brain and spine

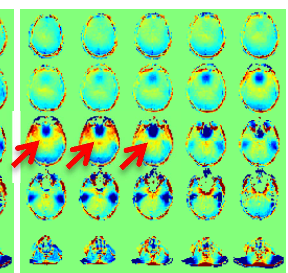

**Fig.4:** Separate shim for each slice

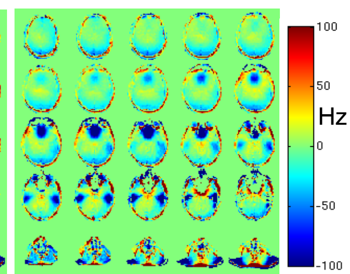


**Fig.5:** Separate shim for each slice + masking

**Discussion:** The slice-based dynamic shim (Fig.4) provides a more homogeneous field than both the conventional single shim (Fig.2) and a separate brain and spinal cord shim (Fig.3) because the linear gradients and frequency offset are set optimally for each slice and need not be compromised for field homogeneity of other slices. Near the frontal sinuses, however, least squares yields poor homogeneity (Fig.4 arrows). This region can be excluded from a least squares calculation since large susceptibility gradients would destroy the signal in typical fMRI gradient-echo sequences with a long echo time. Using an exclusion mask, a more homogeneous field is obtained (Fig.5).

**Conclusion:** We presented a slice-based dynamic shim technique, which calculates shimming from a field map, that optimizes shimming for both the brain and spine regions simultaneously. Compared to the technique in [2], that uses one set of linear shim and center frequency for all brain slices and another set for all spinal slices, our technique offers more freedom in tackling inhomogeneity per slice.

References: [1] Eippert F *et. al.* Elife 2014; 3:e03811. [2] Finsterbusch J. *et. al.* Neuroimage 2013; 79:153-61.
Acknowledgement: General Electric Healthcare. NIH Grants: P41 EV0015891, R01 NS053961, K24 DA029262