A novel technique for spinal fMRI with large volume three-dimensional coverage of the spinal cord

P. W. Stroman[1,2], J. Kornelsen[2], J. Lawrence[2], K. L. Malisza[1,2]

[1]MR Research & Development, Institute for Biodiagnostics, NRC, Winnipeg, Manitoba, Canada, [2]Dept of Physiology, University of Manitoba, Winnipeg, Manitoba, Canada

Introduction

Functional magnetic resonance imaging of the spinal cord (Spinal fMRI) has been developed into a reliable method for studying spinal cord physiology and the effects of injury[1-3]. However, the methods that have been developed require that images be oriented transverse to the spinal cord to take advantage of high in-plane spatial resolution and minimize problems with partial-volume effects. The drawback of this method is that only a relatively small portion of the spinal cord can be imaged unless time is taken to acquire a very large number of transverse slices. Here we present a modification of our established method in which sagittal slices are acquired to cover a much larger extent of the spinal cord. This orientation requires contiguous slices with minimal thickness. The resulting image data must then be reformatted into slices that are transverse to the cord, with smoothing applied in the rostral-caudal direction, to attain a signal-to-noise ratio equivalent to that with our established method. Following a typical fMRI analysis based on correlation with a model time-course, maps of active regions in the spinal cord are then easily represented as thin axial slices or reformatted back into thin sagittal slices to provide greater flexibility for presenting the results. The ultimate goal of this work is to develop spinal fMRI into a practical clinical tool, and to be able to present results in a form that is most effective for clinicians.

Methods

Spinal fMRI studies of healthy volunteers were carried out at 1.5 T in a GE Signa Horizon LX clinical MR system. Data were acquired with single-shot fast spin-echo imaging with a 12 cm x 12 cm field of view and 128 x 128 matrix, and an echo time of 36 msec. K-space data were zero-filled to 256 x 256 prior to reconstruction. Eight contiguous slices, each 2.8 mm thick, were selected to span the cord, requiring a repetition time of approximately 10 seconds. Thermal stimulation of the palm of the right hand was used to elicit activity in the cervical spinal cord, with 15 °C cold used for stimulation and 32 °C as a baseline during rest periods. The temperature transition occurred in one TR period (10 sec). A block design was used with stimulation periods of 60 seconds duration interleaved with rest periods of 60 seconds. Data were analyzed using custom-made software written in MatLab (The MathWorks Inc., Natick MA). Sagittal slices were combined into a three-dimensional volume and interpolated to obtain cubic voxels 0.5 x 0.5 x 0.5 mm^3, and the volume was then re-sliced transverse to the spinal cord. Prior to analysis a line was drawn manually on a mid-line sagittal image along the anterior edge of the spinal cord and this was used as a reference for the spinal cord position and curvature. This enabled smoothing in the rostral-caudal direction across consistent anatomical areas. Active voxels were identified with a T-value threshold of 2.0, corresponding to a p-value threshold of 0.05, and were plotted in color over a gray-scale average image of the volume. This volume was then also reformatted back into thin sagittal slices so that results could be viewed in both orientations.

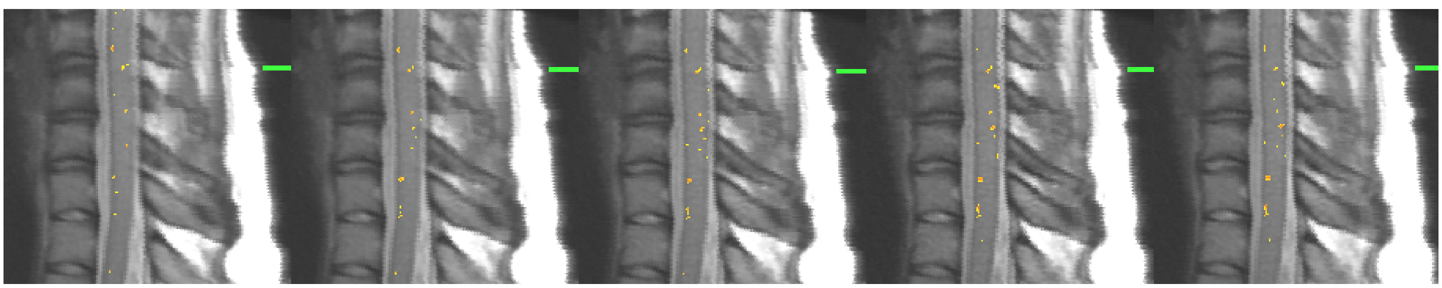

Figure 1: An example of 5 reformatted sagittal slices from one volunteer, spanning 2.5 mm across the right side of the cervical spinal cord (lateral to medial going from left to right in the image). The dorsal side is to the right, and the rostral direction is toward the top. Sensory activity can be seen in the right dorsal horn spanning from the 6th cervical spinal cord segment (marked approximately with the green line) down along the 7th and 8th segments. Some motor reflex activity is also observed.

Results and Discussion

Spinal fMRI consistently demonstrated activity in the right dorsal horn (ipsilateral to the stimulation) corresponding to sensory activity, at roughly the 6th to 8th cervical spinal cord segments. Activity was also observed in the ipsilateral ventral region, and around the central canal, at the 7th and 8th cervical spinal cord segments, demonstrating a motor reflex response. The distribution of activity observed was consistent with spinal cord neuroanatomy and with results of previous studies, with mildly noxious cold stimulation. The data acquired with our modified method demonstrates a continuum of activity along the rostral-caudal direction of the spinal cord, at the expense of lower resolution in the right-left direction. The consistency of results obtained indicates that the loss of left-right resolution does not significantly diminish the sensitivity. The benefit of this method is that we are able to better demonstrate the distribution of activity in the rostral-caudal direction, and also to detect activity along a relatively large portion of the spinal cord. The modified method also enables results to be presented in thin sagittal slices, to be more readily compared with conventional MRI. This method thus provides a clear advantage over a small number of axial slices for the development of a practical clinical assessment tool.

References

1. Stroman *et al.* NeuroImage 17, 1854-1860, 2002.
2. Stroman *et al.* Spinal Cord. (in press), 2003.
3. Stroman *et al.* Magn Reson.Med. 48(1), 122-127, 2002.