Characterization of Spinal Cord Motion: A Source of Errors in Spinal FMRI?

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Introduction

Functional magnetic resonance imaging has been utilized to map areas of neuronal activity within the spinal cord. Such activity maps have been shown to be more reliable across groups of subjects, whereas the results of individual experiments often show minor inconsistencies, overlooking areas of known activity. The most likely explanation for such omissions in these individual activity maps is motion, which would average over a large group of trials, thereby explaining why grouped data is more accurate than data from an isolated experiment. Though it is believed that the spinal cord moves within the spinal canal, there has been very little published regarding the cause, magnitude, direction, or timing of this motion. Therefore, motion of the cord must be characterized before more accurate neural activity maps can be obtained from individual spinal fMRI experiments. Since heartbeat is thought to be the principal factor contributing to spinal cord motion, the objective of the current experiment is to characterize the magnitude, direction, and timing of spinal cord motion relative to the cardiac cycle.

Methods

Healthy volunteers were imaged using a 3T Siemens Magnetom Trio with an anterior neck coil and upper elements of a spine phased-array coil, as receivers. Excitation pulses were transmitted using a body coil. High-resolution images of the cervical spinal cord were acquired with a cardiac gated, fast spin-echo sequence. The in-plane resolution was 0.52 x 0.52 mm, with a single 3 mm thick mid-line sagittal or coronal slice (in separate studies), 384 x 192 matrix, 200 x 100 mm FOV, 2 averages, TE = 16 msec, and an echo-train length of 13. In separate acquisitions the images started at 0, 200, 400, 600 and 800 msec after systole, and data was acquired within less than 200 msec.

In separate studies, a cardiac-gated imaging sequence was used to produce images at 18 different phases of the cardiac cycle with a “turbo-FLASH” sequence, with a single 5 mm thick sagittal slice, mid-line through the cervical spinal cord, TE/TR/flip = 1.8 msec/40.3 msec/60 degrees. Image data were analyzed using custom-made software in MatLab, by measuring the separation of the spinal cord edge from the edge of the spinal canal, as a function of the phase of the cardiac cycle.

Results

Analysis of spinal cord position (relative to the edge of the spinal canal) demonstrates that the spinal cord moves within the canal as a function of the cardiac cycle. The motion involves a flexion of the cord, primarily in the anterior/posterior (A/P) direction, and is dependant on the rostral/caudal (R/C) position. Analysis of sagittal slices revealed peak motion of the cord to be between 1 and 1.5 mm A/P, whereas at some R/C locations, the motion was negligible. Analysis of coronal slices has shown right/left (R/L) motion of the cord to be negligible at all R/C positions within the field of view. Motion in the R/C direction is difficult to identify and has not been observed, but based on the anatomy, no significant motion is expected to be possible in this direction. The most rapid motion was apparent at roughly 600-800 msec after systole, but no quiescent period without any cord motion was observed.

Conclusions

By characterizing spinal cord motion as a function of the cardiac cycle, the sensitivity and reliability of spinal fMRI results can be increased. Cardiac-gated acquisitions have been shown to improve spinal fMRI results, but because there is no quiescent period in the cord motion cardiac-gating methods are not expected to be fully effective.