Functional Magnetic Resonance Imaging (f-MRI) of the Human Cervical Spinal Cord

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INTRODUCTION

Non-invasive investigation of spinal cord function using f-MRI would contribute greatly to the diagnostic and follow-up assessment of patients with spinal cord injury improving the information presently obtained with standard motor and sensory neurological tests. Our aims in this investigation were to determine whether f-MRI signal can be obtained from the spinal cord using an 1.5-T clinical MR system, and to determine whether the f-MRI signal is spatially localized to specific anatomical areas according to the functional organization of the spinal cord gray matter.

METHODS

Activation conditions consisted of upper extremity motor tasks (flexion-extension) in 16 right-handed volunteers, thermal stimulation of the hand (ice bag contact) in 4 volunteers, and electrical stimulation of the median nerve (3-9 mA, frequency: 8 Hz) in 4 subjects, each performed in a block design (30s on / 30s off). These tasks were selected to activate specific neuroanatomical areas (i.e. motor, sensory, or combined sensory-motor pathways) of the cervical spinal cord.

Imaging was performed in the transverse plane, centered on the lower cervical spinal cord covering vertebrae C4-T1 (C5-C8 cervical cord segments). The in-plane spatial resolution was kept to 1mm or better, and a slice thickness to 7.5 mm. Spatial saturation anterior to the spine was used to suppress motion artifacts from breathing and swallowing. The flow-compensation was applied to reduce artifacts from CSF flow. After an initial phase comparing various imaging algorithms at an 1.5-T MR system, a Turbo Spin Echo (5000ms/40ms/90º/7mm/120mm) sequence was used more consistently for the functional acquisitions. Data analysis included rigid-body registration to reduce any effects of motion during the data acquisition. Statistical parametric maps of significant activation were generated on a subregion of the images containing the spinal cord to avoid the effects of changes in the tone or position of the surrounding muscle. Analysis was performed in the time domain on a pixel by pixel basis by computing the cross-correlation with the exercise paradigm, after applying a three-point median filter. A correlation coefficient $R = 0.4$ was used for the correlation resulting in a $P < 0.05$ (1,2).

RESULTS

An average intensity increase of the fMRI signal of 3-7% with return to baseline during rest periods was observed in all experiments. The areas of activation were predominantly ipsilateral to the hand involved in the exercise and seen between the levels of the C6-C8 spinal cord segments.

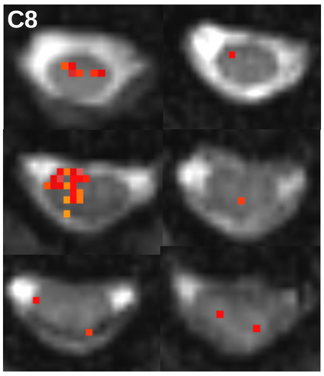

Fig. 1

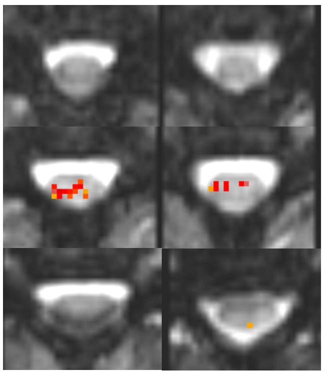

Fig. 2

MOTOR TASK

The f-MRI signal during motor tasks occupied the ipsilateral intermediate zone of the spinal cord grey matter (interneurons in Rexed's lamina VII) with an extension in the ventrolateral direction (motor neurons in Rexed's lamina IX). [Fig.1]. In almost all motor experiments, foci of activation in the dorsal horn and in the contralateral grey matter were less consistently found probably representing closely related sensory areas, involved in the regulation of motor control. Upper extremity motor tasks involving different myotomes were spatially localized to particular anatomical segments according to the craniocaudal segmental organization of the spinal cord and brachial plexus (hand and wrist more caudally at C7-C8, whereas elbow more cranially at C5-C6)

THERMAL STIMULATION

Activation was detected in the ipsilateral dorsal horn spanning Rexed's laminae I to VI, corresponding to sensory input [Fig. 2]

Prominent activity was also observed in the intermediate lamina VII, which contains propriospinal neurons that project to other regions within the same and adjacent spinal cord segments and to higher levels of the CNS

ELECTRIC MEDIAN NERVE STIMULATION

The median nerve was stimulated repetitively at the wrist to induce twitching of the thumb. Activity was not selectively localized to the dorsal or ventral horn suggesting activation of both sensory and motor fibers in the median nerve. [Fig.3]

The time course of the signal intensity increase was time-locked to the timing of the activation conditions.

DISCUSSION

The fact that we observe similar intensity signal changes (3-5%) with both sensory and motor stimuli and the tendency to be localized in the expected areas of neuronal involvement enhances our believe that we are observing physiological changes related to neuronal activity in the spinal cord and not motion or artefact-related changes. These preliminary results support the findings of Stroman et al (1,2) that intensity changes related to neuronal activation can be detected in the human cervical spinal cord. Further investigations are needed to establish the levels of intra- and inter-subject reproducibility which can be achieved with spinal cord f-MRI.

REFERENCES

1. P.W.Stroman et al., Neuroimage 17, 1854-1860 (2002)
2. P.W.Stroman et al., Mag. Res. Med., 20, 1-6 (2002)