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Functional MR Imaging of the Cervical Spinal Cord by Use of Electrical Stimulation at LI4 (Hegu)

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Abstract— **Purpose: To investigate the cervical spinal cord mapping on electrical stimulation at LI4 (Hegu) by using ‘Signal Enhancement by Extravascular water Protons’ (SEEP) – fMRI, and to establish the response of acupoint-stimulation in spinal cord. Methods: Three healthy volunteers were underwent low-frequency electrical stimulation at LI4. Meanwhile, a single-shot fast spin-echo (SSFSE) sequence was used to perform functional MR imaging on a 1.5 T GE Signa MR system. Cord activation was measured both in the sagittal and transverse imaging planes and then analyzed by AFNI (Analysis of Functional Neuroimages) system. Results: In the sagittal view, two subjects had an fMRI response in the cervical spinal cord upon electrical stimulation at LI4. The localizations of the segmental fMRI activation are both at C6 through T1 and C2/3 cervical spinal cord level. In the transverse imaging plane, significant fMRI responses could be measured in the last subjects locating at C6/7 segment, the cross-sectional localization of the activity measured in the spinal cord was most in terms of the ipsilateral posterior direction. Conclusion: The fMRI technique can be used for detecting with activity in the human cervical spinal cord by a single-shot fast spin-echo sequence on a 1. 5T GE clinical system. Investigating the acupoint-stimulation response in the spinal cord using the spinal fMRI will be helpful for the further discussion on the mechanisms of acupuncture to spinal cord diseases.**

Keyword— **spinal fMRI; cervical spinal cord; electrical stimulation**

I. INTRODUCTION

FUNCTIONAL magnetic resonance imaging (fMRI) has become a well-established method for mapping neuronal function both in human brain and spinal cord. Using the BOLD-fMRI for investigating the acupuncture response in human brain has been proven to be a powerful tool for the mechanisms research of acupuncture to Central Neural System diseases [1-3]. However, to date, there is no report on the spinal fMRI underwent with acupoint stimulation.

The purpose of this study was therefore to investigate the neuronal activity in cervical spinal cord assessed with SEEP-fMRI [4-7] using a low-frequency electrical stimulation at LI4. And then make our primary discussion on the acupoint-stimulation response in the spinal cord.

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II. METHODOLOGY

Stimulation paradigm: Three healthy volunteers with no history of neurological disease, degenerative disorder, or spinal trauma (all male, mean age 24.3 years, range 24 – 25, all right-handed) were investigated.

Electrical stimulation at the LI4 of right hand was performed in all three subjects, with constant current pulses at a frequency of 5 Hz. The stimulation current (35–40mA) was adjusted to induce. All electrical stimulations and measurements were performed with superficial carbon electrodes suitable for use in a high–magnetic field environment. Electrical LI4 without stimulation (rest) was applied in 35-s epochs alternating with 35-s epochs stimulation. Images were acquired repeatedly during alternating rest and stimulation periods for five times, resulting in a total of 52 time points recorded with the beginning of R1=49s.

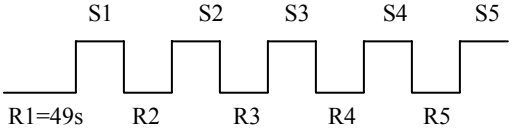

Fig.1: The stimulation model of the electrical simulation at the LI4

MR Protocol: Images were acquired with a 1.5-T MR GE imaging system that was equipped with a standard receiver neck coil. Head fixation was achieved with two foam cushions. The MR imager room was dimly lit, and the subjects were instructed to close their eyes during the experiment.

The functional imaging session for the sagittal images was obtained using single-shot fast spin-echo imaging sequence with the following parameters: Flow compensation, No phase wrap. TR = 1065.0ms, TE = 42.4ms; Bank Width: 32 KHz; FOV: 16cm x 16cm; Matrix: 128 x 128; NEX 1; 7slices; section thickness: 2.8mm; spacing: 0.5mm. Slices were oriented transverse to the spinal cord and the thickness was adjusted so that every second slice was aligned with either the inter-vertebral discs or centers of the vertebrae, spanning the entire cervical cord. Adjusting the slice thickness accordingly resulted in a slice thickness range of 7.0–7.5mm, and the

parameters were as follows: TR = 1065.0ms, TE = 42.4ms; Bank Width: 32 KHz; FOV; 12cm x 12cm; Matrix: 128 x 128; NEX 1; 7 slices; section thickness: 7.0mm; spacing: 2.0mm. Spatial saturation pulses were applied to eliminate signal from surrounding areas to avoid aliasing and to reduce motion artifacts arising from regions anterior to the spine.

Data analysis: The image data were analyzed within the framework of the general linear model in AFNI (Analysis of Functional NeuroImages: Robert W. Cox, Medical college of Wisconsin). The first two volumes in each scan series, collected before equilibrium magnetization was reached, were discarded. Then, all volumes were registered to the volume collected nearest in time to the high-resolution anatomy. Next, a spatial filter with a root-mean-square width of 4mm was applied to each echo-planar volume. The response to each stimulus category compared with the fixation baseline was calculated using multiple regressions. All areas that showed a response to any stimulus

III. RESULTS

All three subjects are feeling of numbness, but no soreness while being underwent with a low-frequency electrical stimulation at LI4. Cervical spinal cord activation was observed in all three subjects.

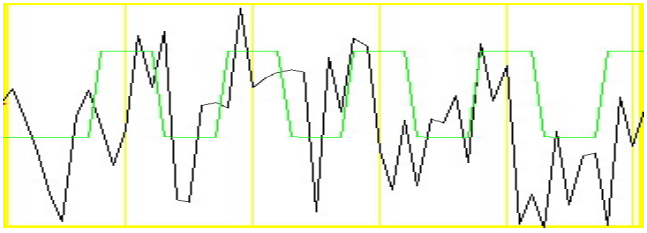

Fig.2 illustrates a typical example of the spinal fMRI activation pattern with electrical stimulation at LI4

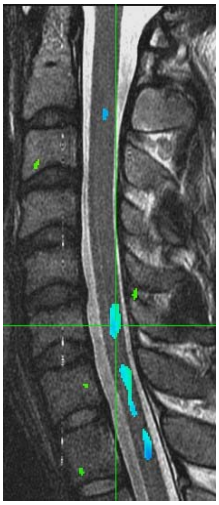

Fig.3: In the sagittal view, two subjects had an fMRI response both in the upper and lower cervical spinal cord. The localizations of the segmental fMRI activation are C6 through T1, and C2/3 level as well.

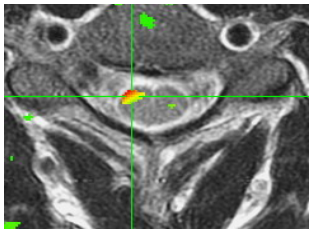

Fig.4: In the transverse imaging plane, significant fMRI responses could be measured in the last subjects locating at C6/7 segment, the cross-sectional localization of the activity measured in the spinal cord was most in terms of the ipsilateral posterior direction.

IV. DISCUSSION

1. Contrast mechanisms for spinal fMRI: Functional MRI (fMRI) of the cerebral cortex using BOLD contrast is currently a well-established technique. In recent years, some authors have additionally shown the principal possibility of BOLD imaging at the level of the spinal cord [8-10]. Another spinal fMRI technique is base on signal enhancement from extravascular water protons (SEEP) effect, which was recently demonstrated to contribute to fMRI signal changes in the spinal cord [1-4]. The proposed mechanism of SEEP is a local increase in tissue water content arising from an altered fluid balance due to the normal production of extracellular fluid and cellular swelling. When blood flow increases, the intravascular pressure also increases, particularly on the arterial side of the capillary system. This pressure change alters the normal fluid balance and increases movement across blood vessel walls into extracellular space, resulting in a slight increase of water protons near active neural tissues. T2-weighted images were often obtained with SSFSE sequence [11-14] that provides an overall better images quality and temporal resolution. Our tentative suggests that the SEEP-fMRI technique can be used for detecting with activity in the human cervical spinal cord by a single-shot fast spin-echo sequence on a 1. 5T GE Clinical System.

2. Primary discussion on the spinal cord aviation using an electrical stimulation at LI4: Acupuncture originated in ancient China and has been used by Chinese and other Eastern peoples to promote and maintain health [15]. However the underlying mechanisms of acupuncture to the Central Neural System, especially to the spinal cord diseases remain unclear. Many studies of acupuncture on experimental animals have shown that it modulates the neuro-endocrine and circulatory systems, among others in the injury spinal cord [16-17]. Studies on human beings were limited by the lack of noninvasive methods, but neuroimaging techniques such as functional MRI (fMRI) provide new tools for such studies. Our work is the preparation for the study on acupuncture response in human spinal cord by fMRI technique. In summary, during the acupoint electrical stimulation at LI4, activations were found at two main locations:

1. Dorsally in the lower cervical segments（C6 through T1）at a level corresponding to the dermatome where the stimulus was applied. The location of the LI4 is on the dorsum of the

hand, approximately at the midpoint of the second metacarpal bone, in the belly of the first interosseus drsalis muscle. It is overlying the superficial ramus of the radial nerve. The most likely explanation for these activations would be reflex activity in pathways from low threshold cutaneous afferents into the spinal dorsal horn. The activations described were consistently seen during electrical stimulation at LI4.

2. The upper cervical spinal cord at the level of the C2/3 segments. These activations were seen almost invariably. The activations were visible in both two subjects with a low-frequency electrical stimulation at LI4. These activation cannot be fully explained with the knowledge based on the reflex pathway in the spinal cord nervous system, and may be related to exists of the special transmission channel of acupuncture. It is said to promote the circulation of blood and 'Qi', the harmony of 'Yin' and 'Yang', and the secretion of neurotransmitters, thus maintaining the normal functions of the human body and providing comfort. The results suggest that acupoint stimulation may evoke the neural activation in spinal cord through such a special transmission channel.

V. CONCLUSION

In this study we report acupoint-stimulation-induced activation of the cervical spinal cord. To date, this is the first demonstration of acupoint-induced spinal cord activity in humans using fMRI. Results indicate that electrical stimulation at LI4 elicits an integrated response from two main levels of the cervical spinal cord. Activation in the lower cervical segments（C6 through T1）was at the level corresponding to the dermatome where the stimulus was applied. We propose that the activation of the upper cervical segment, in particular C2/3 level, maybe correspond to the special transmission channel of acupuncture. The functional MR imaging technique base on SEEP effect can be use for detecting with activity in the human cervical spinal cord, and for the further study on the spinal response to the acupuncture action.

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