Somatotopic Representation and Cortical Thickness of Primary Motor Cortex in Bell’s Palsy: Preliminary Study

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Abstract—The main objective of this research is to investigate how the somatotopic representation of motor cortex changes along no-use of affected facial muscles. We use Bell’s palsy patients who has degenerated peripheral lesion and muscle paralysis.

Using MR imaging technology and electromyography, we compared the functional activity and connectivity of BOLD signal and the cortical thickness on the relevant motor cortex.

We found less functional activities, fewer functional connectivity, and thinner cortical thickness in the relevant brain ROI to the muscle contraction, which is showing a negative neuroplasticity. Then it could be speculated that this negative plasticity might induce the poor prognosis of muscle paralysis in Bell’s palsy.

I. INTRODUCTION

EVEN though the Bell’s palsy, an idiopathic unilateral facial nerve paralysis, has fairly good prognosis, once the patients carry their symptoms to a chronic phase, the paralysis has been known to be hardly recovered and lasts in the rest of their life with partially or fully degenerated peripheral neuropathy.

The central control from motor related regions in brain might be circumscribed by the peripheral neuropathy so that their coordinated command could not completely or, more frequently, partially reach to effector organ, a group of facial muscle. The constant blockage will induce a neuroplasticity, which is an ability of the human brain to change as a result of one’s experience. After the link to effector organ is disconnected, this experience might be able to actually change both the brain's physical structure (anatomy) and functional organization (physiology).

One of the examples is the neuroplasticity after amputation. Even though many patients suffer from the ‘phantom pain’ which is thought to result from disorganization in the brain map and the inability to receive input from the targeted area, eventually an adaptation process will be undertaken and somatotopic organization for sensory inputs from the amputated part will disappear.

Cortical organization, especially for the sensory systems, is often described in terms of homunculus [1]. For example, sensory information from the Index finger projects to one cortical site and the projections from the fifth finger target in another site. As a result, somatotopic organization of sensory inputs to the cortex, cortical representation of the body resembles a map or homunculus. While the sensory systems have been relatively well studied, the motor system’s homunculus has not been clear. Especially a change of patient’s homunculus has not been reported.

First aim of this study is to explore the cortical site corresponding different muscles that are innervated by the same motor nerve bundle, facial nerve. The second one is to investigate how the somatotopic representation of motor cortex changes along no-use of affected facial muscles. Furthermore, thirdly we hypothesized that the 4-5% poor prognosis is due to the negative neuroplasticity in the central nervous system as well as to the neuropathy of the peripheral nerve.

Thus, we explored the motor-related brain regions where the peripheral neuropathy could affect the neural plasticity. We compared the functional activity and connectivity of BOLD signal and the cortical thickness and white matter connectivity on the relevant motor cortex.

II. METHODS

A. Subjects

We first made an initial screening interview via phone. This was done to distinguish potential subjects from those not meeting eligibility criteria in accordance with the Internal Review board of Kyung Hee University.
Before conducting the experiment, we asked the subjects to do some training in order to observe and monitor their facial movement and to ensure they are familiarized with the experimental paradigm. From this training, any mistakes during the experiments could be eliminated or at least being minimized.

B. EMG measurement

The motor tasks conducted were upward movement of forehead, outward movement of mouth, and movement of index finger as a control. The root mean square (RMS) changes of the electromyography (EMG) activity at risorius m. and frontalis m. were calculated in order to test the muscles contraction. In this experiment, blocked and even-related designs were used for the application of the motor task. For the blocked design, we had 10 seconds of movement mode (on task) and 10 seconds of resting mode (off task) while for the even related design, 1 second of movement with the different interstimulus interval (ISI) was applied.

C. Experimental Design

During the experiment (which was conducted at the first 1 or 2 months after the attack for the Bell’s palsy patient), the subjects were asked to perform the motor task movements according to our blocked design.

According to our blocked design, we had 10 seconds of movement mode (on task) and 10 seconds of resting mode (off task). We asked the subjects to make 5 movements within the 10 seconds (Fig. 1). The fMRI data that were obtained are brain localization, EPI images (for motor tasks and rest session), structural image and diffusion tensor image (DTI). The motor tasks experiments were lasting for 4 minutes. We divided the motor task sessions into three different tasks that are: index finger (D2) - little finger (D5), mouth-forehead, and purse-frown. Index finger was used due to functional opponent to the other digit, difference anatomical construction, mere degree of freedom of movement and it has large motor representation area than the other digit. In the research conducted by Ferrier [2], he observed that stimulation of the primate precentral motor cortex (Brodmann area 4) near the lateral fissure produced movements of the tongue and mouth. The movement of the forehead is applied as the forehead can still be wrinkled or moved by patient whose facial palsy is caused by a problem in one of the hemisphere of the brain (central facial palsy).

D. Imaging Methods

High-resolution three-dimensional T1-weighted structural imaged of the brain was acquired with the Phillips 3T Scanner for each participant. This scan utilizes a headcoil to acquire one-hundred twenty eight 2.875mm slices with a 50% gap, TE of and TR of 1/2s and 35ms. These data were used for co-registration with fMRI images as well as cortical surface reconstruction and determination of conductivity boundaries for the boundary element method forward solution.

Conventional BOLD functional imaging was performed using a gradient echo T2*-weighted pulse sequence (TR/TE= 2s/35ms, matrix = 2.875x2.875, FOV = 85x230x230 flip angle=90˚, 10 dummy scans, slice thickness=2.5mm). A new prospective motion correction sequence was employed for reducing motion-induced effects. This methodology utilizes a full 3-D rigid body estimation of head movement, obtained by image-based motion detection and real-time adjustment of slice position and orientation. The prospective motion correction will be crucial, as head motion will be one of the limiting factors in achieving long duration scanning for perfusion MRI, BOLD, or T2*-mapping. For physiological monitoring during fMRI scanning, we used Lab Chart 7.0-Pro as the physiological monitoring system in order to monitor the ECG, GSR and respiratory rate of the subjects.

The respiratory rate of the subject was measured by using the ‘pneumobelt’ device which consisted of corrugated silicone tubing with a resting length 22cm and an internal diameter of 2.5cm [3]. This device is compatible with the MRI scanner environment and has been previously utilized during acupuncture fMRI studies. Heart rate variability analyses (beat-to-beat basis for mean, high and low frequency variability and non-linear heart rate complexity) will be performed on the ECG data to quantify subtle effects of acupuncture administration on sympathetic and parasympathetic ANS activity [4][5]. For the ECG data specifically, we also used Datex-Ohmeda Patient Monitors (GE Healthcare, United Kingdom) for the physiological monitoring.

E. Data analysis

The measured EMG signals were calculated respectively using the root mean square (RMS).

For the preprocessing of MRI data, the RETROICOR analysis was done to remove the artifacts due to respiration cycle and cardiac cycle. Functional-Structural coregistration was done to register different brain to each other and to a common space, we performed linear registration in which it translate, rotate, zoom and shear one image to match with each other (FLIRT, FSL). The non-linear method was also being used as it permits reasonable job of compensating for the image (FLIRT, FSL). Then coregistration and conversion to MNI has been done. Multivariate Exploratory Linear Optimized Decomposition into Independent Components

![Fig. 1. The experimental paradigm for the motor task experiment](image-url)
(MELODIC) or motion component filtering was used to decompose 4D data into different interesting spatial and temporal components. It picked out different activation and artifactual components without any model being specified (FSL).

General Linear Modeling (GLM) Data Analysis was done in volumetric data by using the FSL-FEAT in order to identify the specific somatotopic representation regions for six motor tasks and based on the regions, the cortical thickness from T1 anatomical image were measured on the surface model (FreeSurfer).

One data was excluded because gross translational motion exceeded 3mm on an axis. Data were thresholded at $p < 0.001$ (t > 3.38) with a minimum cluster size of 3 voxels with multiple corrections. The data in the volumetric space were transferred to the surface space for the FreeSurfer analysis.

Cortical thickness is one of the most important fundamental measurements for population and longitudinal studies in brain imaging. Cortical thickness was measured from MRI brain images which are basically based on the classification of brain matter into the major tissue classes: gray-matter (GM), white-matter (WM) and cerebro-spinal fluid (CSF) [6]-[8]. Once these surfaces were extracted from the MRI data, surface based method was used by using the Euclidean distance between points on the inner surface to points on the outer surface. We did the cortical thickness based on the log that we obtained from the Recon-All process (FreeSurfer). The thickness of the cortex is a property that can only be properly measured if the location and the orientation of the gray/white and pial surface both are known. The surface of the connected white matter then is refined to obtain subvoxels accuracy in the representation of the gray/white boundary and subsequently deformed outward to find the pial surface [9][10].

In the functional connectivity, the seed voxel approach was used to calculate the correlation between “seed” time series and the time series of the other voxels in the brain. We first defined the region of interest (ROI) of the brain which was made from the group analysis. As the motor cortex area was our concern, we focused on the activation produced by the motor tasks on that particular region and evaluated the differentiation map of the brain. After determining the ROI area, we made the masks for each region and created the seed for the ‘seed voxel analyses’. In the seed voxel analysis, parameters such as the ROI, white matter, cerebro-spinal fluid and the motion parameter were taken into consideration.

### III. Results

#### A. Muscles performance: EMG

For the RMS of EMG, Paralysis group did not show significant contraction level compared to no contraction period (rest) while healthy subjects showed normal contraction level (Fig. 2). It is clearly showing that Bell’s palsy patient has the problem with the peripheral muscle contraction. In future, EMG will be correlated with brain activity as well as electroneuronography (ENoG). If our hypothesis is true, EMG as a objective clinical outcome, is a function of functional and structural brain change (parameters of neuroplasticity) as well as ENoG (a parameter of peripheral lesion).

#### B. Functional activation of Primary Motor cortex

![Brain activity of risorius muscle contraction](image)

Fig. 3. Brain activity of risorius muscle contraction (for outward movement of mouse). Figure shows healthy side of patient. It was compared with lesion side. The proportion of activated area for the movement to whole primary motor cortex was calculated. Recruited cortical area in healthy side was almost twice as big as lesion side.

Fig. 3 shows healthy side is more active that lesion side after two month muscle paralysis, because the motor area might be able to be fed back from muscle maybe via somatosensory area.

#### C. Cortical thickness

Cortical thickness of lesion side of a patient was compared to healthy control group (n=6). The ROI was taken from the brain region which is activated also for risorius m. Patient has obviously thinner than healthy subjects (Fig. 4). Interestingly, both sides of hemisphere showed thinner cortex. See the error bar of health subject. The thickness of patient is far below the error bar.

![Cortical thickness of patient in M1](image)
Fig. 4. Cortical thickness of Healthy group(A) and a patient(B). ROI were taken from the region of risorius m.

D. Functional connectivity

Functional connectivity of brain region for risorius m. was investigated for both of healthy and patient group. While healthy group showed connectivity to supplementary motor area (SMA), cingulate motor area (CMA), ACC and cerebellum as motor related regions, patient group showed just a connection to SMA.

Fig. 5. Functional connectivity of ROI from risorius m. contraction

IV. DISCUSSION AND CONCLUSION

Even though this is just preliminary result with small number of subject (6 health and 2 patient), the results is promising to show a neuroplasticity from peripheral neuropathy. Then it can be speculated that this negative plasticity might induce the poor prognosis of muscle paralysis.

REFERENCES