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The use of Reconstructed 3D Brain Surface Imaging Approachto Identify the Precentralgyrus and Its Detail Function Distribution

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Abstract

To study the use of reconstructed3D brain surface imageto identify the precentralgyrus and its detail functionaldistribution.Method: There are a total of 12refractory epilepsy caseswhich need intracranial electrode implantation according to a preoperative assessment. In these patients, magnetic resonance imaging (MRI) and functional MRI (fMRI) were conducted pre-operation, and a cranial computed tomography (CT) scan was performed after electrode implantation. BrainVoyager software was used for 3D reconstruction of the brain surface by using MRI data, which was integrated with the subdural electrode CT. Based on the characteristics of the shape of the precentralgyrus, the precentralgyrus was marked in the reconstructed brain surface image, and the precentralgyrus and adjasentgyrus were found and identified in the surgical field by comparingthe typical shape of the exposed gyrus in the reconstructed3D brain surface image with that in theintraoperative photographs. The reliability of the precentralgyrus identified by the presentmethod was verified by electrical cortical stimulation (ECS) and fMRI.

Index terms—

The use of Reconstructed 3D Brain Surface Imaging Approachto Identify the Precentralgyrus and Its Detail Function Distribution Jiu-luan Linab ? , Wen-jing Zhoua ? , Guang-Ming Zhanga ? , Yu-QiZhangab ? & Huan-cong Zuoab ¥

Abstract-Objective: To study the use of reconstructed3D brain surface imageto identify the precentralgyrus and its detail functionaldistribution.

Method: There are a total of 12refractory epilepsy caseswhich need intracranial electrode implantation according to a preoperative assessment. In these patients, magnetic resonance imaging (MRI) and functional MRI (fMRI) were conducted pre -operation, and a cranial computed tomography (CT) scan was performed after electrode implantation. Brain Voyager software was used for 3D reconstruction of the brain surface by using MRI data, which was integrated with the subdural electrode CT. Based on the characteristics of the shape of the precentralgyrus, the precentralgyrus was marked in the reconstructed brain surface image, and the precentralgyrus and adjasentgyrus were found and identified in the surgical field by comparingthe typical shape of the exposed gyrus in the reconstructed 3D brain surface image with that in theintraoperative photographs. The reliability of the precentralgyrus identified by the presentmethod was verified by electrical cortical stimulation (ECS) and fMRI.

Results: All the 12 cases were performed 3D brain surface reconstruction and precentralgyruswas found and marked according to the characteristics of precentralgyrus. There were 101 electrodescovering the precentralgyrus and 73 (72%)of them had motor response to electrical stimulation. In the contrast team, (the area which is 1 cm ahead of the precentralgyrusidentied by the reconstructed3D brain surface), the motor response rate was 13% (17/130) ($p<0.05$). During fMRI, 100% of the precentralgyrus and 58% (7/12) of postcentralgyrus was activated during hand movement,with no activation of the areas ahead of precentralgyrus, so there was also significant difference between precentralgyrus and gyrus ahead. Therefore, the precentralgyrus identified by the presentmethod is accurate and reliable.

1 Introduction

uring surgical procedures, identifing the precentralgyrus and then protecting the motor function are crucial for neurosurgeons. However, it is very difficult to accurately find and confirm the precentralgyr-usbyanatomic landmark without the aid of navigation or electricalcortialstimulation. The precentralgyrus is challenging to be identified mainly due to limited exposure, which leads to a lack of an overall impression regarding the shape of the gyrus. Intraoperative blood vessels and gyrus variation also make it difficult to precisely identifythe gyrus.

Reconstruction and representation of the cerebralcortex from magnetic resonance imaging (MRI) plays an important role in the study ofthe structure and function of the brain [1][2][3][4][5][6]. In recent years, there has been a significanteffort towards the development of methods for the cortical surfacereconstruction.

Althoughthe 3D reconstruction of the brain surface has been applied to numerous types of research, to date it has not been used to locate the precentralgyrus, or to locate and protect the motor function area. Electrical cortical stimulation is a standard method to identify theimportant functional areas of the brainfor patients who need to be awakeduring surgery or patients with subdural electrodes [7,8,9,10]. However, it requires multi-point and multi-parameter stimulation (i.e. intensity, frequency and wave width of electric currents), and consequently it is laborious, time consuming and requires patients'cooperation with various tasks. According to previous reports [11,12,13], 71% of patients experienced after-discharge and other side effects by electrical stimulation, which affected the accuracy of positioning [14]. And a false positiveresponseby electrical stimulation will lead to incomplete resection of epilepsy foci, while a false negative responsewill lead to an unexpected loss of function. A hematomaunder the subdural electrodes or brain edema post intracranial electrode implantation-ncausing inhibition or loss of function of local cortex, will result in a false negativeresults by ECS. And false positive results by ECS occur in cases with larger electric current or increased excitability of focal cerebral cortex causing the distant spread effect. fMRI is another common noninvasive method for preoperative functional positioning [15,16,17,18,19]. fMRI provides useful detailed assessment of anatomic features, including deep brain structures. However, the repeatability of functional positioning remains a challenge [20], and the results are not always consistent with invasive examination. At the same time, it also requires patient's good cooperation to complete relevant tasks.

Without the results of fMRI or electrical stimulation for functional positioning, it is difficult to identify and protect the patient's precentralgyrusin the condition of limited exposure, if the epileptic foci is close to the precentralgyrus. It is also a challenge to quickly and accurately locate the patient's precentralgyrusin-traoperation. Therefore, there is an urgent clinical need for an ideal and simple positioning technique to identify the precentralgyrus. With the development of the 3D brain surface imaging technology, positioning and identification of the precentralgyrus can be applied in clinical practice. The present study aimed to identify the precentralgyrus according to the characteristics of the precentralgyrusby using the technique of the 3D brain surface reconstruction.

2 II.

3 Methods

Twelve patients (8 female, 4male,mean age 21.4 years), with refractory epilepsy, who required implantation of intracranial electrodes (subdural and deep electrodes) in the frontotemporaland central region according to preoperative assessment, were enrolled. Functional positioning was conducted during the interictal when the patient was in a good condition without seizureat least one hour before and after the test. Patient characteristics including seizure frequency and electrode coverage are shown in Table 1. theBrainVoyager software; 2). Register:post-implantation CT images were registered to the reconstructed brainsurface. We employed a mutual-information-based linear transform to align the MRI and CT in3DSlicer software [22].

3) The 3-D brain surface was overlaid with semitransparent CT images using our in-house registration toolbox.The course can be completed in 30 minutes. The electrode position was compared to intraoperative photographs, and the registration error was less than 3 mm according to some anatomical marks. Figure **??**C c) Identification and marking of the precentralgyrus According to the anatomical features of the brain gyri, the central sulcus and the precentral sulcus were set as front and back borders, and the shape was parallel to the coronary position. From the lateral fissure extending upward to the longitudinal fissure, it continued backward to the postcentralgyrus.The superior frontal gyrus, middle frontal gyrus, inferior frontal gyrusends at the precentralgyrus and is vertical to it. The inferior frontal gyrus ends and integrates into the bottom of precentralgyrus, middle frontal gyrus ends and integrates into the middle of precentralgyrus and the superior frontal gyrus ends and integrates into the top of precentralgyrus which is near the longitudinal fissure. Figure **??**A After the reconstructed 3D brain surface image was integrated with subdural electrodes, we drew the range of the precentralgyrus using a black line in FOTOSHOP through direct visual comparison. (Figure **??**BC)We then marked on the numbers and points of electrodes that covered the precentralgyrus, and identified the neighboring gyri, which mainly included: postcentralgyrus, superior frontal gyrus, middle frontal gyrus, and the inferior frontal gyrus. d) Comparison of brain surface imageand surgical photos, tags for gyri confirmation

During surgery, precentralgyrus and other gyri were identified in the photos based on typical characteristics of gyri's shape (usually use precentralgyri) by comparing the 3D brain image with the surgical photos.Furthermore, we can take the subdural electrodes as reference to identify gyrus.So the 3D brain surface image led to clear exposure of anatomy and function of gyri one after another in the operating field.(Figure **??**D) Figure **??** e) Verification for electrical stimulation Electrical stimulation locates the precentralgyrus and verifies the identification of precentralgyrus by brainsurface image. When electrical stimulation is conducted, the precentralgyrus demonstrates the most obvious motor response from the frontal pole backward. The electrodes which produced a motor response to the electrical stimulation were marked on the brain surface; it can be helpful to see whether the points appearing as a motor response were located on the precentralgyrus.

These points appearing as a motor response can be classified as either within the precentralgyrus or outside the range of the precentralgyrus.

The proportion of motor response points in all electrode points on the precentralgyrus was calculated (between 0 and 1). A percentage closer to 1 indicates that the positioning of the precentralgyrus is more reliable. In the contrast team, precentralgyrus move forward 1 cm(i.e.2electrodes aheandprecentral sulcus), the percentage of motor response points was also calculated.(Figure **??**,Table **??** 2) The reliability of our method for locating the front border of the precentralgyrus can be verified statistically by comparing the motor response in the two areas. The posterior border extending backward 2 cm should be in the position of the postcentralgyrus, which is also an important functional brain region. This study did not focus on the position of the posterior border but identified the frontier border of the precentralgyrus, to ensure safety during surgery on epileptogenic foci at the back of the frontal lobe. There are three explanations for motor response points outside the precentralgyrus: 1.) caused by the spread of electric current; 2.) the abnormal or potential motor area or part of the sports network, and 3.) a false positive reaction due to movement by the patient at the time of stimulation. Figure **??** f) Process and positioning of fMRI Patients performed three differentmotor tasks (i.e., left hand, right hand, tongue) in 12 second task blocks interspersed with12 second resting blocks. Each task blockcontained only one type of movement and therewere 6 blocks for each type of movement in the entire session.MRI was acquired using Philips Achieva 3.0, with the 8-channel SENSE head coils. Visual cues were presented during each task block using the Psychophysics Toolbox4.31. Structural images were acquired using a sagittal magnetization prepared rapid gradient echoT1-weighted sequence (TR 2s, TE 2.37 ms, flip angle 90°, slice number 180, 1-mm isotropicvoxels). fMRI were acquired using echo planar imaging sequences (TR 3s, TE30ms, slice number 47, 3-mm isotropic voxels). fMRI data were processed using SPM8(Wellcome Department, UCL). The pre-processing included slice timing correction, rigid bodycorrection for head motor, and normalization for global mean signal intensity across tasks.fMRI results were integrated with 3D brain surface image through BrainVoyage software to determine whether the brain region representing motor response was in the precentralgyrusas located by our method. (Figure **??**2, Table **??** g) Functional mappingand epilepsy foci resection All the 12 patients received epileptogenic zone resection.Acording toictal and inter ictal discharge byECoGmonitoring,the epileptogenic zone was found.The surgical plan was made.The resection area and function area was draw in the 3D brain surface and surgical photograph.We can predictwhether functional defectsoccurred post operation.(Figure 3)III.

4 Results

The precentralgyruswas marked in all 12 cases on the 3D brain surface image and theprecentralgyrus was identified in intraoperative photographs base onthe characteristics of gyrus in 3D image. The anatomy and function of brain gyri below theelectrodes which coveredboth exposed area and non exposed area was identified.

The precentralgyrus was found and marked in the 3D brain surface image according to its anatomical characteristics. There were 101 electrode sites on the precentralgyrus and 73 (72%) of these had a motor response to electrical stimulation. In the contrast team, in the area which is 1cm ahead of precentralgyrus, there were only 17 of 130 (13%) electrodes that had a motor response ($p<0.05$)(Table 2),demonstrating that there is a significant difference between the motor response to electrical stimulation in the area ahead of the frontier border of precentralgyrus (i.e., precentral sulcus) and the area behind it.

5 cases,in whichthe resection scope extended into precentralgyrusidentified by this method,developed hemiplegia of the hands and paralysis,but they recovered well half year later. (Figure **??**3) The other 7 cases, in which the resection scope was in front of the precentralgyrus, did not develop postoperative hemiplegia,although3of them had a motor response to ECS in the resection scope. positions were located inthe precentralgyrus nearestto the central sulcus. 7/12 of the activated areas reached the postcentralgyrus, and no activation was foundin front of the precentralgyrus. Soprecentralgyrus was 100% activated, but the brain area ahead precentral sulcus was 0% activated.There was significant difference between precentralgyrus and the area ahead it. Therefore, the reliability of this method for locating the precentralgyrus was verified by fMRI. **??**Figure.2, **??**able.3) In addition, the precentralgyrus identified by the 3D brain surface reconstructionimage was consistent with electrical stimulation and fMRI positioning. IV.

5 Discussion

The positioning of precentralgyrus in brain surface image is very safety and reliable, and can locate the motor area both easily and simply. Also, it could give the whole scopy of motor area for protecting it. Therefore, it will avoid false negative results from positioning by ECS on the motor area. In addition, it is also the most reliable and safe method for protection of brainmotor function. And we were not worry about the resection of the area in front of precentral, because it generally will not lead to a lack of primarymovement. Although some patients with this area resectionmay lead to temporary lack of function of supplementary motor,they will recover very well later.In addition, our study do not focus on pathological shift patients, therefore in the absence of the anatomical shift, almost no primary motor area appears in front of the precentralgyrus, and few case reports show the existence of a variable motor area in front of the precentralgyrus, primarily due to the pathological shift [23,24].

Without pathological shift, the so-called variable motor activation area in front of the precentralgyrus (located by fMRI or electrical stimulation) is often a supplementary motor role, and it cannot cause irreversible loss and can quickly restore motorfunction. Characteristics of motor distribution in the precentralgyrus are clear, and motor function is distributed in various areas of the precentralgyrus. Until recently, only a few motor functions could be stimulated by ECS or tested by fMRI, such as limb and tongue movement, which are the most common functions. Thus, 3D brain surface positioning by precentralgyrus is both a safe and effective way to protect motor function, and the process is simpleand does not require the cooperation of patients. This method has clear advantages, particularly for patients who are unable to cooperate to perform the task of fMRI or ECS. It has been validated that this method is highly consistent with fMRI and ECS in positioning the precentralgyrus. ECS is used to verify the positioning of precentralgyrus in brain surface image, and the positive rate of ECS is high. In the contrast team, the positive rate with ECS was only 17% in the area two electrodes in front of the precentralgyrus, confirming the reliability of thismethod. Movement 3D-fMRI also demonstrated reliable positioning the precentralgryrus by our method. The activated movement area in fMRI is usually located to the side of the precentralgyrus near the central sulcus. The postcentralgyrus can also be activated. The motor area stimulated by ECS is mostly within the precentralgyrus, anda few extended to thepostcentralgyrus, but few located in front of the precentralgyrus, which may be related to current transmission. The slightdifference between the activation may be associated with the two motor reaction mechanisms. Subjects, who had spontaneous movementdruingmovement-fMRIscan, can have activation of proprioception, primary motor regions and associated motor regions of the brain. In contrast, movement stimulated by ECS is a stimulating movement, and such movement was the primary movement or supplementary movement. We need differentiate these two movement stimulated by ECS, because brain area of primary movement located in precentralgyri,whereas supplementary movement located in supplementary motor area(SMA).

Based on the MRI scan, CT scan and intraoperative photographs, the whole process of reconstruction, integration and identification requires approximately 1 hour. This is less than the complex electrical stimulation operation, and unlike other methodologies there is no need for patient cooperation. The method used in this study to locate the precentralgyrus by 3D brain surface image, may be complementary and verification for electric stimulation and evoked potential, and also for high frequency ECoG motor function positioning (in the cases with subdural electrodes implanted).It can also be independently used to locate the precentralgyrus and to protect motor function during surgery in the situation when patients cannot complete electric stimulation or when subdural electrodes cannot be implanted.

There are several advantages associated with 3D brain surface imaging. It provided an easy method to confirm the sensorimotor area, and also provided a method to verify each other with ECS or fMRIin positioning sensorimotor area. In addition to the location of the functional brain areas, the corresponding anatomical gyrus can be easily located during surgery by comparing it with the shape of the gyrus, making location of the brain function more complete and comprehensive. For those cases that cannot complete electrical stimulation because of brain edema or bleeding in the brain after subdural electrode implantation, this positioning method is a viable alternative. It is also helpful in terms of epileptic foci localization. It can clearly and dynamically display EEG origin and spread, and evolution of symptoms of epilepsy coincides with anatomical function of the involved brain areas, which clarifies the mechanism of epileptic seizures and improves the accuracy of epileptic foci localization. Through visualization of electrode and brain surface, the surgeon's vision will be expanded and also recognition of anatomical features and functions of operated gyri will be improved. In addition, it also can found the false negative or false positive electrode identified by ECS or fMRI in movement function mapping. Therefore, it is a reliable guarantee for movement function because it gave the scopy of precentralgyrimore completelythan the methods of ECS or fMRI.

Rapid positioning will benefit the surgical plan. The main disadvantage of electrical stimulation is that it is tedious and lengthy. Electrical stimulation needs at least 10 to 20 pairs of electrodes to locate, and the electric current needs to slowly increase (1-10 mA). Therefore, just a simple test requires 1 to 2 hours. Not only ECS makes patients tired, but also there is risk that after discharge potentially inducing seizure, thereby preventing it from further positioning in danger point electrode testing [25,26]. Therefore, this testing method is a challenge both for patients and doctors. In this study, we found that the function location can be completed in approximately 1 hour, with high safety and reliability. Electrical stimulation positioning can only test a pair of electrodes once, and the 3D brain surface image positioning can locate the whole precentralgyrus immediately,and also the testing time is significantly reduced, which is applicable to all patientsprovided they have had an MRI scan.

Brain surface imaging approach of positioning the precentralgyrus is very practical. Since the function distribution and arrangement of the precentralgyrus is becoming clearer, as long as the precentralgyrus is identified during surgery, then it is possible to gather detailed information of motor functiondistribution. (Figure .4). And the table.4 show the distance betweentdiffenent motor area in another 3 patents in our centre who receiced intraoperative electrical coticalstimulation. So we can get the detail distribution of motor function in the precental gyri. At the same time, if the precentralgyrus is set as a reference, partition and specific function of frontal lobe can be clearly marked, which can provide important guidance during epilepsy surgery. Thus the symptoms of epilepsy and the gyri involved can be connected and located, and surgeons have greater assurance for resection of the epilepsy foci. On the contrary, electrical stimulation positioning by subdural electrodes can only locate brain areas which arecovered by electrodes, and the function of the areas without electrode coverage cannot be evaluated. Becauseepilepsy foci often sets gyrus as a boundary, and the range of the resection may be extended to areas without electrode coverage, or extended to the unexposed areas. Therefore, there is no doubt that the 3D imaging approachhas greater advantages for identifying the gyrus as well as assessing the associated function. In some cases, there may be difficulties or uncertainties to identifythe precentralgyrusby 3D brain surface image. Then, we need overlap themotor activated fMRI results on the 3D reconstructed brain surface image, which can also help to find the precentralgyrus on the 3D constructed brain surface quickly and precisely.

In conclusion, it is both feasible and reliable to identify the precentralgyrusby using 3D brain surface imaging technique. Also, it can confirm and protect precentralgyrus in epilepsy surgery without needing intracranial electrodes implantation. In cases with subdural electrodes implantation, it can also help to overcome the limitation of exposed surgical field and the subdural electrodes, and ease the difficulty of gyrus identification, which is important to protect functional areas and to resect epilepsy foci. There were 3 patients ' results of intraoperative direct corticalstimulation.The above table show the distance between different motor area on the precentralgyri.Acording these data ,we can get the detail information of motor functiondistribution like figure.

3

Figure 1: 3)

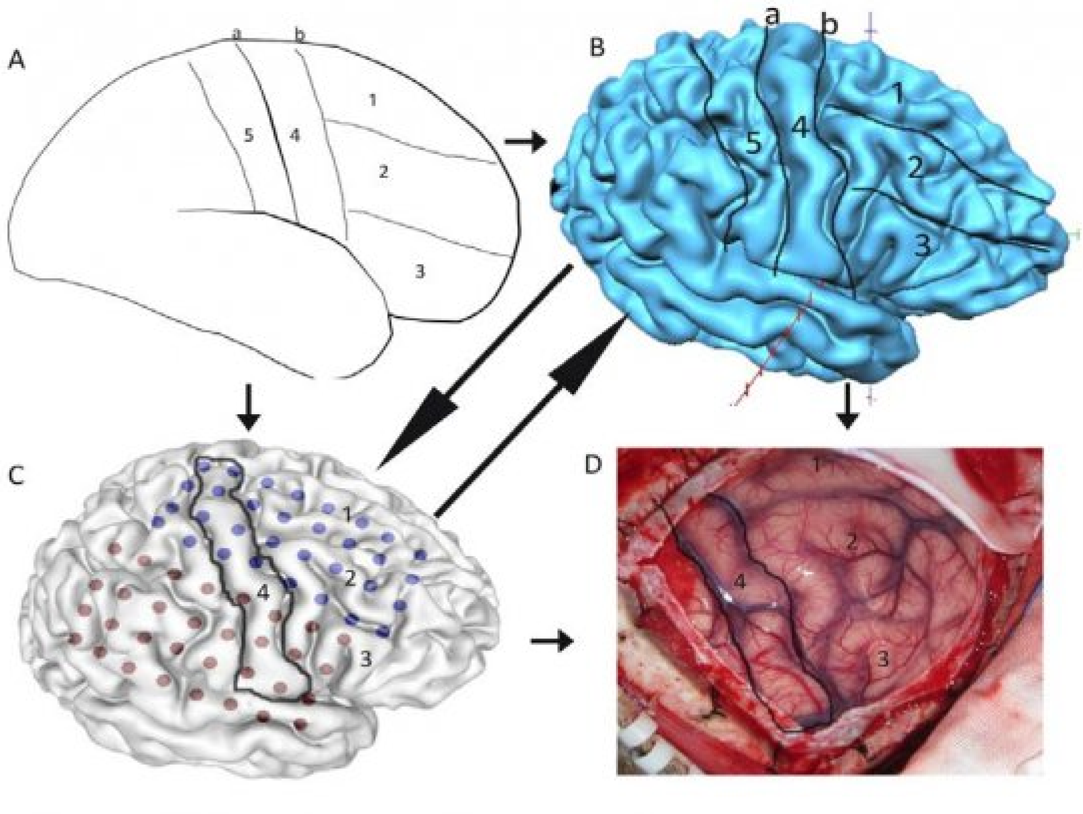

Figure 2:

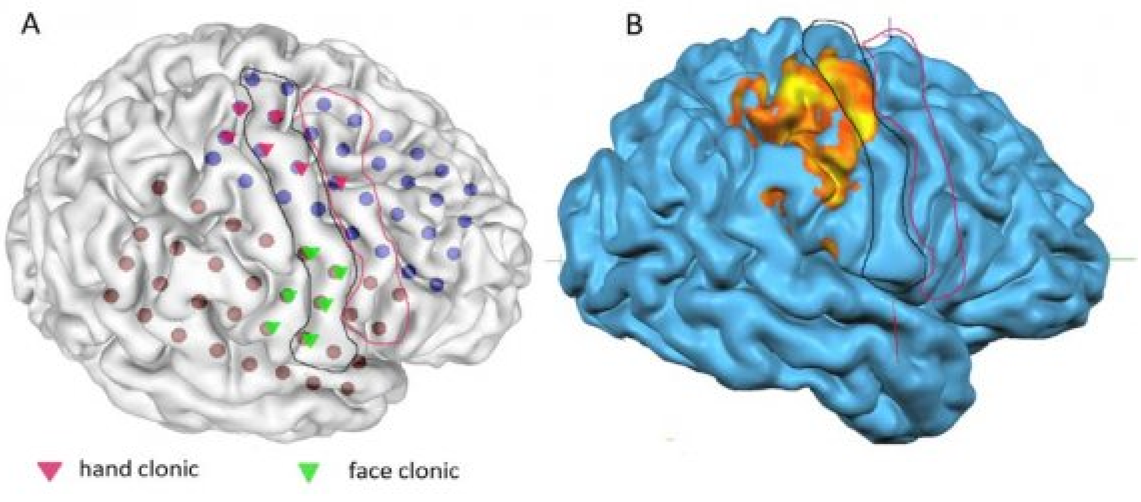

Figure 3:

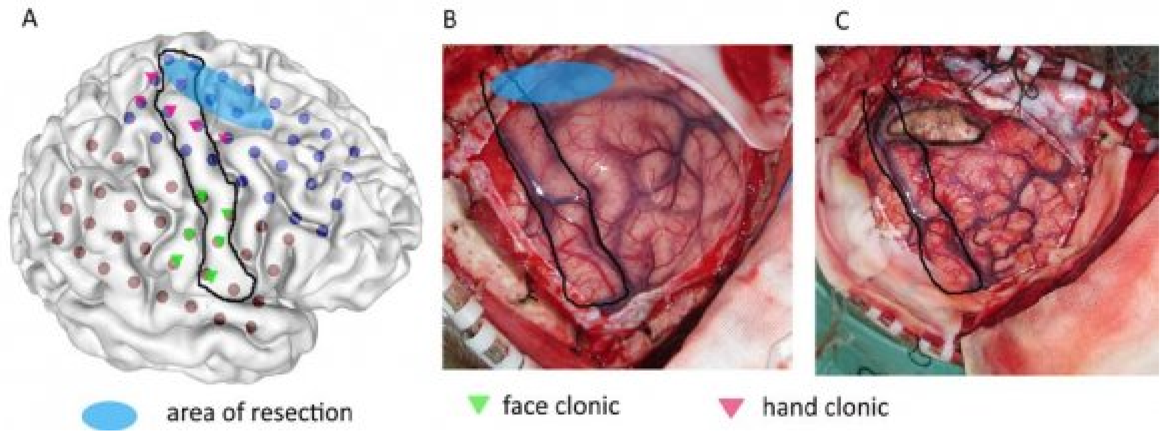

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Figure 4: Figure 4 :

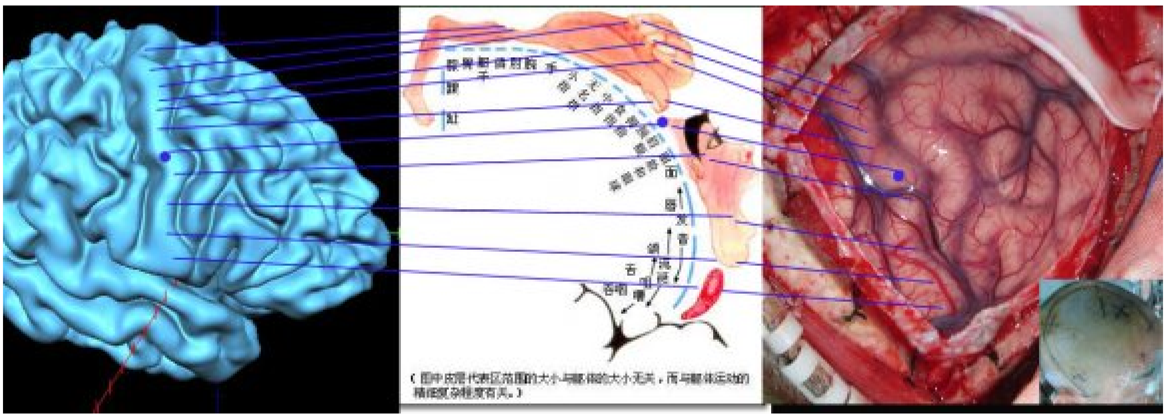

Figure 5:

1

: Clinical data

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Figure 6: Table 1

2

Group 1

Figure 7: Table 2 :

3

patient	Group1 precentralgyrus actived by hand	Postcentral gyrus	Group2 Area of 2electrodes ahead precentral sulcus
1	+	-	-
2	+	-	-
3	+	+	-
4	+	-	-
5	+	+	-
6	+	+	-
7	+	+	-
8	+	+	-
9	+	-	-
10	+	+	-
11	+	-	-
12	+	+	-
rate	100%	58%	0%
?2	P<0.01		

Figure 8: Table 3 :

4

Patient	Tongue-mandibular mm	mandibular-mouth mm	mouth-eyelid mm	eyelid-neck mm	thumb-fore-middle finger mm	fore-middle finger-ring mm	Pinky-wrist mm	Wrist-shoulder mm
1	6	5	8	6	6	6	7	5
2	5	5	7	7	5	6	7	6
3	6	7	7	6	7	7	6	6
average	5.7	5.7	7.3	6.3	6	6.3	6.7	5.7

Figure 9: Table 4 :

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