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Clinical Study

The threshold of cortical electrical stimulation for mapping sensory and motor functional areas

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ABSTRACT

This study aimed to investigate the threshold of cortical electrical stimulation (CES) for functional brain mapping during surgery for the treatment of rolandic epilepsy. A total of 21 patients with rolandic epilepsy who underwent surgical treatment at the Beijing Institute of Functional Neurosurgery between October 2006 and March 2008 were included in this study. Their clinical data were retrospectively collected and analyzed. The thresholds of CES for motor response, sensory response, and after discharge production along with other threshold-related factors were investigated. The thresholds (mean ± standard deviation) for motor response, sensory response, and after discharge production were 3.48 ± 0.87, 3.86 ± 1.31, and 4.84 ± 1.38 mA, respectively. The threshold for after discharge production was significantly higher than those of both the motor and sensory response (both $p < 0.05$). A negative linear correlation was found between the threshold of after discharge production and disease duration. Using the CES parameters at a stimulation frequency of 50 Hz and a pulse width of 0.2 ms, the threshold of sensory and motor responses were similar, and the threshold of after discharge production was higher than that of sensory and motor response.

1. Introduction

Identification of functional cortical areas and the origin of epilepsy are prerequisites for the safe and effective removal of the seizure focus in rolandic epilepsy. Since cortical electrical stimulation (CES) has been applied in clinical practice, it has been widely accepted as the "gold standard" of functional brain mapping, due to the direct nature of the cortical stimulation and objective response.[1,2] However, it has also been found that individuals can respond differently to electrical stimulation.[3–5] Some patients may develop somatic sensory and motor responses with obvious after discharge (and possibly epilepsy) after even minor stimulation, while others may require much greater stimulation. This had led to the conclusion that there are differences in the threshold (the minimal stimulus intensity that develops a somatic response) for CES. Determination of the threshold is the basis of mapping functional areas using CES in clinical practice. It has been speculated that this disparity in minimal stimulus intensity is caused by individual differences in growth/development, lesion characteristics, disease duration, and variable cortical excitability between age groups.[5–7] However, there has not been sufficient clinical data to prove any hypothesis.

The present study retrospectively analyzed data pertaining to the CES of 21 patients with refractory rolandic epilepsy. The CES used subdural electrodes to identify the seizure focus and to localize the functional areas in an attempt to determine the relationship between them. The purpose of the study was to investigate the response threshold of the motor and sensory cortex to electric stimulation in rolandic epilepsy patients, and to determine if a relationship exists between this threshold and factors such as disease duration, patient age, and pathological changes in epilepsy patients. Conclusions could then be used as a scientific basis for personalized CES functional mapping in clinical practice.

2. Materials and methods

2.1. Patients

Patients were included in the study if they met the following criteria: (1) they had refractory epilepsy that required surgical treatment because of failed standard drug therapy; (2) their electroencephalogram (EEG) indicated that the seizure originated in or around the rolandic area, or the seizure focus was strongly suspected to be in the rolandic area; (3) brain MRI indicated that the seizure focus neighbored the rolandic area (subdural electrodes were implanted to localize functional areas and identify the relationship between functional areas and seizure focus); and (4) the

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brain cortex mapping data proved that the seizure originated in or around the rolandic area, and the seizure originated from the rolandic areas. CES was needed to identify the relationship between the functional areas and the seizure focus.

Patients who failed to meet the above requirements were excluded, and those that met the following two criteria were also excluded: (1) young age or with mental or intellectual disorders who might have poor cooperation; and (2) hematoma or effusion following the implantation of intracranial electrodes, which could affect the result.

According to the aforementioned inclusion and exclusion criteria, a total of 21 patients with rolandic epilepsy who underwent surgical treatment in the Beijing Institute of Functional Neurosurgery of Xuanwu Hospital between October 2006 and March 2008 were included in the present study. The study patients included 17 men and four women, aged 12–44 years, with a mean age of 20 years. The age at disease onset ranged from 0 to 25 years, with a mean of 9.8 years. The duration of disease ranged from 0 to 30 years, with a mean of 10.8 years. MRI revealed 10 patients with lesions and 11 patients without lesions. All patients underwent implantation of intracranial electrodes, pre-surgical CES functional mapping, and the surgical removal of the seizure focus.

2.2. Pre-surgical evaluation

Standard pre-surgical evaluation included medical history, age at time of surgery, age at disease onset, clinical symptoms, physical examination of the nervous system, ictal and interictal EEG, neuroradiological examinations including MRI, a neuropsychological assessment, and other examinations if necessary (positron emission tomography, single photon emission computed tomography and magnetoencephalography). The approximate position of the seizure focus was determined by a comprehensive analysis of the pre-surgical assessment to best identify a position for the implantation of subdural electrodes.

2.3. Implantation of subdural electrodes

Implantation of subdural electrodes was carried out in all 21 patients. The electrode had an appearance similar to a grid or a strip made of stainless steel disks, with each disk containing a 5 mm diameter of exposed surface embedded in silastin at the center. A kerf was designed at the center of the seizure focus identified pre-surgery. Fig. 1a presents a typical rolandic kerf. The subdural electrodes were implanted in the most concentrated and evident site of discharge as indicated by electrocorticographic data and pre-surgical evaluation. Digital imaging was used to photograph the implantation of the electrodes in surgery (Fig. 1b), and post-implantation imaging was used to confirm the placement (Fig. 1c). Dexamethasone (10 mg) was given to each patient immediately prior to surgery and was gradually tapered over 3 days to reduce post-operative discomfort.

2.4. EEG monitoring and CES functional mapping

Generally, EEG (DaVinci Programmable Digital Signal Processors, Texas Instruments, TX, USA) monitoring was performed 1–2 days after the implantation of subdural electrodes, and the ictal and interictal EEG were recorded to identify the seizure focus. Seizures were captured by EEG at least twice. CES mapping was conducted 3–4 days post-implantation to localize the sensory, motor, and language functional areas; however, the present study only focused on the assessment of sensory and motor functions. Electrical stimuli were presented using a Nicolet–Viking IV Constant Current Stimulator (Natus Medical, San Carlos, CA, USA), which generated a rectangular pulse at a rate of 5 Hz or 50 Hz.[8] In the current study, CES functional mapping was performed using 50 Hz stimuli with a pulse duration of 0.2 ms. Current strengths of 1.0–8.0 mA were employed with a train duration of 3 s and an intertrain interval of 20 s. Stimuli at each electrode (using the adjacent electrode as reference) started at 1.0 mA and increased by 1.0 mA increments for each subsequent stimulation until a functional alteration was achieved, an after discharge was recorded, or 8 mA was reached. The stimulation threshold was defined as the intensity of the current that produced signs of contralateral limb or facial sensory or motor function. Each parameter for the effective stimulation threshold of sensory and motor function was summarized. A patient's threshold response to electric stimulation was calculated by averaging the stimulation thresholds at different electrode sites.

2.5. Stimulation response

A primary motor response was defined as a localized movement of the contralateral body in response to stimulation of the cortex while the patient was at rest. A simple isolated movement, such as contraction of the contralateral eyelid, cheek, tongue, hand, or foot are such examples. Movement of the arm was limited to a movement within an isolated joint, such as the wrist or elbow. Movement of the hand was often characterized by the simultaneous extension or flexion around several fingers at the joints.[9] Primary sensory responses were defined as discrete sensory

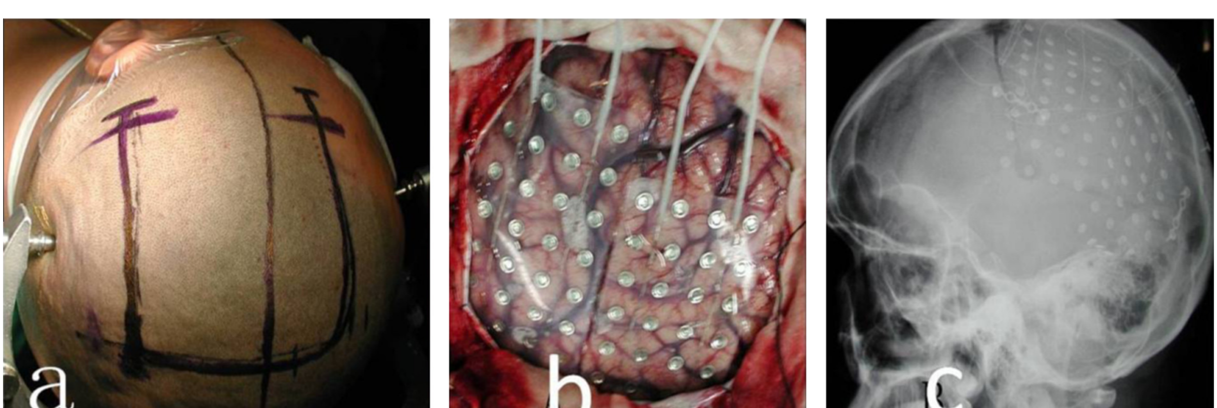

Fig. 1. Perioperative photography showing (a) a rolandic skin flap, (b) axial view of the implantation of the electrodes at surgery, and (c) sagittal radiography showing the placement of the electrodes post-surgery.