Experimental Study on Epilepsy Treatment Using Electrical Stimulation of the Pig Motor Cortex Based on Deep Brain Stimulation

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Abstract. Epilepsy is a common chronic brain disorder, affecting approximately 50 million people worldwide, with over 9 million patients in China. Current treatment methods primarily include drug therapy and surgical intervention. However, drug therapy is often associated with long treatment cycles and significant side effects, while deep brain stimulation (DBS) technology, due to its safety and efficacy, has gradually become the preferred surgical option. This paper, based on deep brain stimulation technology, explores how to achieve targeted current in specific brain regions while minimizing impact on other critical areas through multi-electrode stimulation of the pig motor cortex. The experiment utilizes an adjustable power supply to precisely control current, voltage, and frequency, ensuring the accuracy and safety of electrical stimulation. The results demonstrate that optimizing electrode placement and stimulation parameters can significantly enhance current flow in targeted brain regions. This study provides new insights for the treatment of neurological disorders.

Keywords: Deep brain stimulation, Epilepsy treatment, Pig brain experiment, Neural regulation.

1. Introduction

Epilepsy, a chronic brain disorder, affects around 50 million people globally, and in China, the number of patients has exceeded 9 million, with an increasing incidence rate year by year. It is a chronic non - communicable brain disease characterized by recurrent episodes, sometimes accompanied by loss of consciousness, urinary and fecal incontinence, and brief involuntary twitching of a part of the body or the whole body. The frequency of seizures in patients ranges from once a year to multiple times a day [1]. The randomness and complexity of epilepsy can chronically disrupt the daily lives of epileptic patients, affect their physical and mental health, and even endanger their lives. Due to limitations in economic and medical conditions, many epileptic patients cannot receive appropriate treatment. Therefore, it is necessary to develop long - term and effective treatment methods to help epileptic patients.

Current treatment methods for epilepsy mainly include drug therapy and surgical treatment. According to investigations, most epileptic patients can control epileptic seizures through long - term drug therapy. Common therapeutic drugs include Clonazepam and Phenytoin [2]. However, drug therapy has certain drawbacks. For example, patients with drug - resistant epilepsy cannot relieve their symptoms through drug treatment. Thus, surgical treatment becomes the final choice for many people.

Mature surgical treatments can be divided into two options: resection and electrical stimulation. Compared with drug therapy, surgical treatment has a more significant effect. Patients can clearly feel the remission of epileptic symptoms, and the treatment cycle is relatively short. For patients with drug - resistant epilepsy, although surgical resection of the epileptogenic focus can significantly improve symptoms, it has risks such as damage to important functional areas and a high postoperative recurrence rate. Among surgical treatment methods, the treatment method using

a brain pacemaker has become the preferred choice for epilepsy treatment due to its safety and effectiveness [3].

The principle applied by the brain pacemaker is deep brain stimulation (DBS). Deep brain stimulation is a technology that modulates the neural activity of specific brain regions by implanting electrodes and applying high - frequency currents. It has been successfully applied in neuropsychiatric diseases such as Parkinson's disease and obsessive - compulsive disorder. The basic principle of using DBS to treat epilepsy is to modulate the neural activity of specific brain regions through electrical stimulation, inhibit abnormal electrical activities, and thus reduce the frequency and severity of epileptic seizures [4]. However, its application in epilepsy treatment still faces two major challenges: firstly, the spatiotemporal complexity of the abnormal discharge network makes it difficult to accurately locate the stimulation target; secondly, during the DBS treatment process, electrodes need to be inserted into the deep brain, and traditional single - electrode stimulation is likely to cause interference to non - target area neural activities, which may aggravate cognitive or motor function damage. In response to the above problems, we propose to locate the target brain region by stimulating the cortical area, so as to avoid the limitations of non - target brain area activation and tissue damage caused by invasive operations.

We chose the motor cortex as the target area for this experiment, which has important clinical significance and high feasibility. Focal epilepsy has a high incidence rate among epileptic patients, and the motor cortex is one of the origin areas of focal epilepsy seizures, making it of great research significance. Moreover, since the motor cortex is part of the outer structure of the cerebral cortex [5], performing surgery on it can reduce damage to other brain regions.

We selected ex vivo living pig brains for the experiment, which not only improves the credibility of the experiment but also reduces the experimental complexity and cost. When stimulating with electrodes, due to the high impedance of the cell membrane, the current mainly conducts through the intracellular fluid. In dead pig brains, due to cell death and rupture, intracellular substances enter the intracellular fluid, resulting in significant changes in its composition, and completely ignoring the impact of nerve cell activities on the experiment, so the credibility of the experimental results is not high. In - vivo experiments have extremely high requirements for experimental equipment, are cumbersome in steps, and consume a lot of human and material resources. Selecting ex vivo living pig brains can effectively solve these problems. Choosing ex vivo living pig brains also avoids ethical issues. Pigs, as non - primate large mammals, are subject to relatively low ethical review restrictions in most countries, and have a higher public acceptance than non - human primate experiments.

This experiment can partially fill the gap in large - animal ex - vivo brain research. The core innovation of using ex vivo living pig brains as an experimental model lies in their high anatomical and functional similarity to the human brain, which significantly enhances the clinical translation potential of the research. The size of the pig brain (about 1/3 of the human brain), the structure of cortical sulci and gyri, the white - matter - to - gray - matter ratio (about 60%), and the characteristics of blood vessel distribution are highly matched with those of humans, enabling it to more realistically simulate the diffusion path of current in brain tissue (such as conduction along white - matter fiber tracts) and the complex responses of neural networks. Compared with rodent models, the pig brain directly supports the parameter verification of clinical - grade electrical stimulation devices (such as deep - brain stimulation electrodes), avoiding the distortion of the electric field distribution caused by its small volume. At the same time, its blood vessel network and metabolic characteristics provide a more human - like experimental platform for the study of pathological mechanisms (such as ischemia and epilepsy). It can also serve as a reference for the placement of electrodes when treating endogenous epilepsy in the motor cortex, effectively reducing unnecessary waste of human and material resources during the experiment.

Therefore, the subsequent content structure of this paper is as follows: Section 2 elaborates on the experimental methods and processes, including how to design the cortical electrical stimulation experiment and the preparatory work before the experiment; Section 3 presents the experimental

results and analysis; Section 4 discusses the application prospects of the research results in fields such as minimally invasive surgery and automated parameter regulation, and looks ahead to the expansion of DBS technology for multiple diseases.

1.1 Section Headings

1.1.1 Sub heading

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2. Experimental Methods

2.1 Experimental Background

In view of the limitations of traditional deep - brain stimulation technology in epilepsy treatment, such as non - target brain area activation and tissue damage caused by invasive operations, this study proposes a new strategy for precise electrical stimulation based on the cerebral cortex. The aim is to regulate downstream epilepsy - related nuclei through non - invasive or minimally invasive methods.

Currently, both theoretical and clinical experiments indicate that high - frequency current electrical stimulation (130Hz to 180Hz) can effectively inhibit epilepsy or reduce the frequency of epileptic seizures [6]. On this basis, to verify the effectiveness and safety of this strategy, this study used ex vivo fresh pig brains as the experimental model and systematically carried out a three - stage progressive experiment. First, the electrical stimulation device and signal acquisition system were used to verify the signal transmission of the ex - vivo brain - spinal cord and quantitatively evaluate the stimulation parameters. Second, a cortical electrode grid array was established. Through electrical stimulation experiments, the stimulation sites that maximized the current density in the target brain region and had the best spatial specificity were screened out. Finally, by comparing the differences in field potential responses between the target area and non - target areas, the spatial selectivity of the stimulation scheme was determined. This experimental design emphasizes the strict calibration of equipment performance and the standardized processing of

biological samples to minimize experimental errors and provide a reproducible framework for the development of precise and minimally invasive neural regulation technologies.

2.2 Experimental Materials and Equipment

Instruments such as adjustable power supplies, oscilloscopes, multimeters, and wires are required for the experiment.

The experimental material is an ex vivo living pig brain. Given that the physiological structure of a pig brain is damaged if it is frozen for too long, and repeated experiments may cause changes in the structure of the pig brain, which in turn affects the results of each experiment, a freshly harvested pig brain is purchased before each experiment and the experiment is completed within 2 hours to ensure the activity and structural integrity of the brain tissue.

2.3 Experimental Preparatory Work

Before performing electrical stimulation on the pig brain, we first evaluated the performance of the surgical wires and conducted detailed tests and analyses of their electrical characteristics under different experimental conditions. We used 7 - cm - long platinum - iridium wires for the experiment and tested them with different magnitudes and frequencies of current under direct - current (DC) and alternating - current (AC) conditions.

In the DC power supply test, the characteristics of the wire were tested using an adjustable DC power supply. The experiment showed that within the range of 0 to 8V, the voltage regulation accuracy was good. When the voltage was adjusted by 1V each time, the deviation between the actual output voltage and the set value was maintained within 0.1V. However, when the applied voltage exceeded 8V, the wire heated up to the point of thermal radiation and luminescence, and this state may have a certain impact on the experiment.

In the AC power supply test, the frequency adjustment range was 0Hz to 1kHz. The waveforms monitored by the oscilloscope were stable and clear. As the frequency increased, the output current and voltage of the power supply also changed stably, and during the duty - cycle adjustment process, the stability of the output signal was not significantly affected. The power supply stability at different frequencies was excellent, with the fluctuations of current and voltage less than 5%, ensuring that the impact of frequency adjustment on electrical stimulation was within a controllable range.

2.4 Experimental Design

Traditional deep - brain stimulation technology uses implanted electrodes to electrically stimulate deep brain regions. Although it has shown clinical efficacy in the treatment of refractory epilepsy, its invasive operation may cause side effects such as non - target brain area activation and nerve tissue damage. Based on this, this study proposes a new method for treating epilepsy with electrical stimulation: precisely locate the specific cortical area of the epileptic focus and apply electrical stimulation to the superficial layer of the cerebral cortex to regulate the downstream target nuclei. To verify the effectiveness of this strategy, we designed a series of electrical stimulation experiments to confirm that cortical stimulation can effectively induce the potential response of the target brain region. Moreover, the specific points for stimulating the pig motor cortex were preliminarily located, providing an important reference for future electrical stimulation treatment of epilepsy.

2.4.1 Experiment 1: Verification of the Effectiveness of Target Brain Region Stimulation

The electrode was used to locate the target brain region, and different appropriate electrical stimulations were applied while measuring at the connection to the spinal cord to prove that the stimulation was effective, that is, it could cause nerve signal transmission, verifying the integrity of the brain's physiological structure.

2.4.2 Experiment 2: Optimization of Cortical Stimulation Points

Centered on the determined target point, a 3×3 electrode grid array was set up within a radius of 5 mm in the surrounding cortical area, conforming to the international 10 - 10 EEG system standard. Electrical stimulations were applied in sequence, and the current of the target nucleus was recorded. After numerous experiments, several excellent points were finally selected to achieve the best stimulation effect on the target area.

2.4.3 Experiment 3: Evaluation of Stimulation Specificity

To verify that the optimal stimulation points minimized the impact on non - target brain regions and ensure the spatial specificity of neural regulation. Among the several excellent points, the impact of these points on other brain regions was verified. Several representative positions were set in other brain regions, and the impact on the representative positions when the excellent points were stimulated was measured. Finally, the goal was to achieve the best stimulation effect on the target points while having a relatively small impact on other points.

3. Experimental Results

3.1 Experiment 1: Verification of the Effectiveness of Target Brain Region Stimulation

We attempted to stimulate the target area with a square - wave signal with a peak - to - peak value of 3V and a frequency of 180Hz and detected the signal at the connection to the spinal cord.

A peak - to - peak value of 1.39V was detected at the spinal cord, and a peak - to - peak value of approximately 1.02V was detected around the spinal cord. This indicates that stimulating the motor cortex caused the transmission of brain signals, proving the effectiveness of the experiment.

3.2 Experiment 2: Optimization of Cortical Stimulation Points

In the selection of stimulation points, we took the standard points FC3, FC1, FCz, C3, Cz, CP3, CP1, CPz around the target motor cortex as the basic points and applied stimulations with different position combinations.

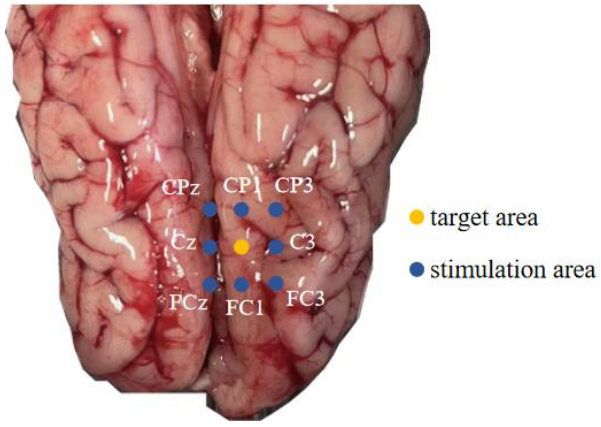

Fig. 1 Schematic Diagram of Stimulation Positions

Table 1. Peak - to - Peak Values at the Target Position When Stimulating Different Points (mV)

	CPz	CP1	CP3	Cz	C3	FCz	FC1	FC3
CPz	/	904	664	648	1420	880	1660	1540
CP1	904	/	960	1200	1250	1210	1880	1480
CP3	664	960	/	1380	760	560	2040	1280
Cz	648	1200	1380	/	332	1140	1500	960

C3	1420	1250	760	332	/	724	1170	1240
FCz	880	1210	560	1140	724	/	1600	1500
FC1	1660	1880	2040	1500	1170	1600	/	1620
FC3	1540	1480	1280	960	1240	1500	1620	/

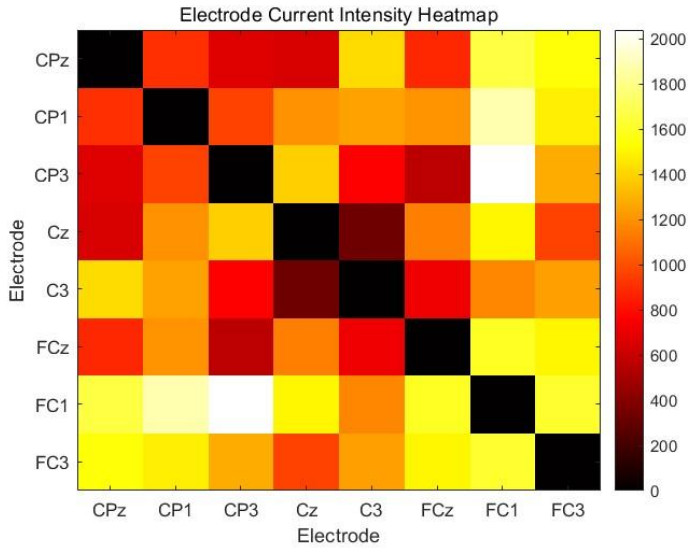

Fig. 2 Electrode - to - Electrode Current Intensity Heat Map

It can be seen that the voltage values at the target position are different when different points are selected for stimulation. The five positions with relatively large voltages in the selection results (FC1, CP1; FC1, CP3; FC1, CPZ; FC1, FCZ; FC1, FC3) were selected as excellent points for further optimization.

3.3 Experiment 3: Evaluation of Stimulation Specificity

Since the current tolerance of different brain regions in the brain is different, to further evaluate the impact of the test points on the current distribution of the whole brain, especially the potential impact on other key brain regions, we selected brain regions important for basic life activities and measured the current passing through other important parts when the test points were stimulated. Representative fixed points were selected for measurement in the parietal lobe, occipital lobe, and temporal lobe respectively.

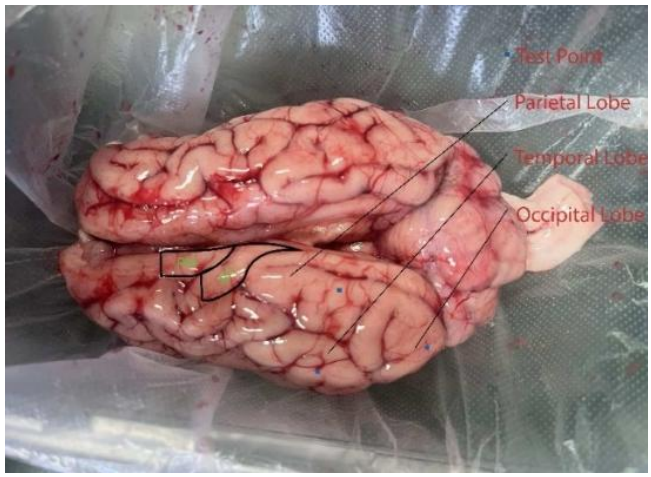

Fig. 3 Schematic Diagram of Representative Positions

After multiple measurements, the following results were obtained.

Table 2. Three Scheme comparing

	FC1,CP1	FC1,CP3	FC1,CPZ	FC1,FCZ	FC1,FC3
Area 1	1.68V	1.38V	1.66V	2.32V	0.624V
Area 2	1.12V	1.36V	1.72V	2.24V	0.752V
Area 3	1.66V	1.04V	1.80V	2.20V	1.08V

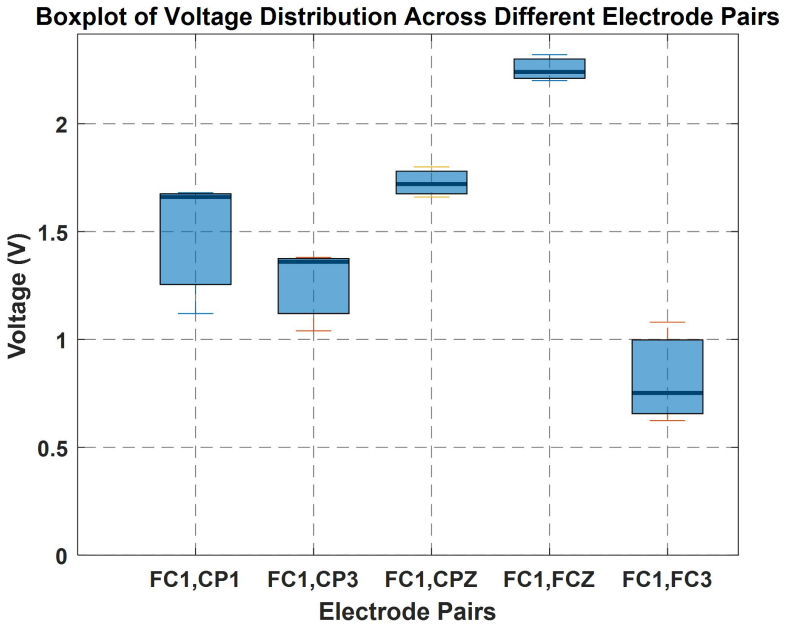

Fig. 4 Quartile Box Plot of Voltage Data

It can be seen that when FC1 and FC3 are stimulated, the overall voltage level of other regions is relatively small. Therefore, the optimal points finally selected are FC1 and FC3.

4. Future Application Prospects

Deep brain stimulation (DBS), as a neural regulation technology, has shown great potential in the treatment of epilepsy. This study on multi - electrode stimulation in pig brain experiments provides strong support for optimizing DBS in clinical applications and finding more effective discharge positions, and offers an effective reference for the application of DBS in epilepsy treatment and clinical treatment [9].

4.1 Minimally Invasive and Flexible

Currently, DBS only has a significant therapeutic effect on diseases caused by the brain regions near the implanted electrodes. When abnormalities occur in other brain regions, it may be necessary to remove and re - implant the electrodes, which can cause damage to the brain.

By investigating and analyzing the stimulation effects of currents with different intensities, frequencies, and other characteristics released from electrodes at different positions, in the future, based on big data analysis and artificial intelligence technology, the optimal electrode implantation position can be selected. After shallow implantation and fixation of the electrodes, combined with disease detection technology to identify the disease type, the current can be made to converge to the corresponding diseased brain region by controlling the currents with different intensities and frequencies released from electrodes at different positions. This technological advancement will make the brain stimulation plan more flexible and precise. When the diseased brain region shifts, it will be possible to stimulate the new brain region by changing the input, reducing the damage to the brain caused by multiple electrode removals and implantations. Moreover, in the daily life of patients, this device can be connected to mobile terminals to flexibly adjust the treatment plan.

4.2 Expanding Research to Multiple Neurological Diseases

The exploration of deep brain stimulation in this study is not limited to epilepsy. In the future, it can also be extended to the research of other neurological diseases, such as Parkinson's disease, depression, anxiety disorder, and obsessive - compulsive disorder. With the continuous development of technology, deep brain stimulation is expected to become a new treatment method for various neurological diseases. By observing and understanding the stimulation activities of brain regions in different diseases, targeted treatment strategies can be developed for different diseases.

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