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FEATURES OF CORTICAL FUNCTIONAL ACTIVITY IN PATIENTS WITH PARKINSON'S DISEASE AFTER DEEP BRAIN STIMULATION IN THE LONG-TERM POSTOPERATIVE PERIOD

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Abstract:
The aim of this study is to analyze the features of cortical functional activity in patients with Parkinson's disease (PD) who have undergone deep brain stimulation (DBS) in the long-term postoperative period. A comparative evaluation of electroencephalographic (EEG) data was carried out in two groups of patients — those who had undergone neuromodulation and those receiving only pharmacological treatment without surgical intervention. The study revealed significant differences in bioelectrical brain activity, indicating the long-term effects of DBS on the functional state of the cerebral cortex and a possible tendency toward both compensatory and maladaptive neural reorganizations over time.

Keywords: Parkinson's disease, deep brain stimulation, neuromodulation, EEG, cortical functional activity, coherence, beta rhythm, alpha rhythm, neurophysiology, long-term period, epileptiform activity, cognitive functions.

INTRODUCTION. Parkinson's disease (PD) represents one of the most common neurodegenerative disorders, characterized by progressive degeneration of dopaminergic neurons in the substantia nigra pars compacta and subsequent development of motor symptoms including bradykinesia, rigidity, resting tremor, and postural instability. While pharmacological treatment with levodopa and dopamine agonists remains the first-line approach, their long-term efficacy is limited by the development of motor fluctuations, dyskinesias, and medication-resistant symptoms in advanced stages of the disease. Deep brain stimulation (DBS) has emerged as an effective surgical intervention for patients with advanced PD who experience inadequate symptom control with optimal medical therapy. This neuromodulation technique typically targets the subthalamic nucleus (STN), globus pallidus internus (GPi), or ventral intermediate nucleus of the thalamus (VIM), delivering continuous high-frequency electrical stimulation through implanted electrodes. The immediate motor benefits of DBS are well-documented, with studies reporting significant improvement in motor symptoms and quality of life measures in the short to medium term. However, the long-term effects of chronic DBS on cortical functional activity remain incompletely understood. While the primary target of stimulation lies in subcortical structures, growing evidence suggests that DBS influences extensive neural networks, including cortical areas involved in motor planning, execution, and cognitive functions. These widespread effects likely contribute to both the therapeutic benefits and potential side effects observed in patients undergoing long-term stimulation. The evaluation of cortical functional activity in the years following DBS implantation is particularly relevant for understanding the neurophysiological adaptations that occur with chronic neuromodulation. Previous studies have primarily focused on short-term changes in cortical activity using electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI). However, comprehensive analyses of cortical functioning years after DBS implantation remain sparse, creating a significant knowledge gap regarding the long-term neurophysiological consequences of this intervention. This study aims to characterize the features of cortical functional activity in patients with Parkinson's disease who have undergone DBS and are in the long-term postoperative period (≥3 years). By examining changes in cortical oscillatory patterns, connectivity, and activation during various motor and cognitive tasks, we seek to elucidate the neurophysiological mechanisms underlying the sustained clinical benefits and potential adaptation phenomena associated with chronic neuromodulation.

Parkinson's disease is a chronic neurodegenerative disorder characterized by impairment of motor function and cognitive processes due to decreased dopaminergic activity. Deep brain stimulation (DBS) is typically used in the late stages of PD to reduce the severity of motor symptoms. Despite the widespread use of this method, its effect on the functional activity of the cerebral cortex in the long-term postoperative period remains a subject of study. EEG is a non-invasive method that allows assessment of the state of cortical neural networks over time.

OBJECTIVE OF THE STUDY: To identify features of functional activity of the cerebral cortex according to EEG data in patients with Parkinson's disease who underwent deep brain stimulation surgery, compared to patients receiving exclusively drug therapy.

MATERIALS AND METHODS OF RESEARCH. For the study, 40 patients diagnosed with PD (stages II-IV according to Hoehn and Yahr) were selected, of which: Group 1 (n=20) — patients who underwent DBS surgery (subthalamic nucleus), monitored 12-36 months after the intervention; Group 2 (n=20) — patients who did not undergo DBS and receiving only drug treatment (levodopa, dopamine mimetics, etc.). The following research methods were conducted on patients: EEG — registration at rest with closed eyes, analysis of rhythm power (delta, theta, alpha, beta), coherence, topographic features. Clinical assessment — UPDRS-III, MoCA, Hamilton Depression Scale. Statistical analysis — Student's t-test, correlation analysis, ANOVA.

RESULTS OF THE STUDY: Analysis of electroencephalographic data showed significant differences in bioelectric activity between patients who underwent deep brain stimulation surgery (Group 1) and patients exclusively on drug therapy (Group 2). In patients of Group 1 (DBS), the following was noted: an increase in beta rhythm power (13-30 Hz) in prefrontal and central leads, especially pronounced in the right hemisphere ($p < 0.05$). This fact may indicate an increase in the functional activity of the motor zones of the cortex in the long-term period after stimulation. Decreased severity of alpha rhythm (8-12 Hz) in the occipital and parietal regions ($p < 0.01$), which may indicate a decrease in the level of basic cortical inhibition and a change in the interaction between the cortex and subcortical structures. In 7 patients (35%), epileptiform patterns were observed: sharp waves, paroxysmal theta bursts, predominantly in the frontal leads. Such changes were absent in the group without neurostimulation. In patients of Group 2 (without DBS), bioelectric activity corresponded to a moderately altered age pattern: alpha rhythm prevailed with preservation of interhemispheric symmetry, coherence was within age norms. The study of coherence showed: in Group 1 — increased intrahemispheric coherence in the beta range between frontal and central zones (especially on the right), which is probably associated with functional restructuring of cortico-subcortical networks after DBS. In Group 2, more pronounced interhemispheric coherence was noted in the alpha range, especially in the occipital leads, which reflects the stability of background cortical activity without surgical intervention. A statistically significant correlation was found between EEG parameters and clinical-functional data: in patients of Group 1, an inverse correlation was observed between the severity of theta activity in the frontal leads and cognitive indicators on the MoCA scale ($r = -0.63$; $p < 0.01$). This indicates a possible connection between frontal dysrhythmia and decreased cognitive functions. Beta rhythm power positively correlated with results on the UPDRS-III scale ($r = 0.58$; $p < 0.05$), which may indicate an associated effect of DBS on motor activity. Additional analysis showed that the longer the period after DBS surgery (>24 months), the more pronounced deviations were observed on the EEG, including: increased focal theta and beta activity in the frontal and temporal leads; appearance of unstable delta components at rest; moderate decrease in coherence between fronto-occipital zones.

CONCLUSIONS: The obtained data confirm that in the long-term period after DBS, patients with PD exhibit persistent changes in the functional activity of the cerebral cortex. Increased beta rhythm power and altered coherence may indicate long-term restructuring of neural networks involved in motor control. Decreased alpha activity and epileptiform patterns, on the contrary, may indicate maladaptive changes requiring monitoring, especially in patients with cognitive decline. Deep brain stimulation has a significant impact on the bioelectric activity of the cortex in patients with PD in the long-term postoperative period. EEG changes are both compensatory and potentially risky in nature. The results emphasize the need for long-term neurophysiological monitoring and individual selection of stimulation parameters.

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