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CAPABILITIES OF MAGNETIC RESONANCE IMAGING IN PARKINSON'S DISEASE



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ПАРКИНСОН КАСАЛЛИГИДА МАГНИТ-РЕЗОНАНС ТОМОГРАФИЯНИНГ ИМКОНИЯТЛАРИ

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ВОЗМОЖНОСТИ МАГНИТНО-РЕЗОНАНСНОЙ ТОМОГРАФИИ ПРИ БОЛЕЗНИ ПАРКИНСОНА

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Резюме. *Паркинсон касаллиги (ПК) марказий асаб тизимининг сурункали дегенератив касаллиги бўлиб, нигростриатал тизимдаги нейронларнинг прогрессив йўқолиши билан тавсифланади. ПД марказий асаб тизимининг сурункали прогрессив нейродегенератив касаллиги бўлиб, дофаминергик нейронларнинг дегенерацияси туфайли ҳаракат бузилиши, когнитив дисфункция ва вегетатив бузилишларга олиб келади. Клиник ташхис одатда аломатлар пайдо бўлганидан кейин қўйилади, аммо замонавий нейровизуализатсия усуллари, шу жумладан магнит-резонанс томография (МРТ) касалликни эрта аниқлаш имкониятини беради. Ушбу мақолада ПДда МРТнинг диагностик аҳамияти, жумладан, нигросома-1 сигналини аниқлаш, диффузион тензор тасвирлаш (ДТИ) ва функционал МРТ (фМРТ) таҳлил қилинган. Бугунги кунда касалликларни эрта аниқлаш, қиёсий ташхислаш ва кечишини баҳолаш неврологиянинг муҳим муаммоларидан бири бўлиб қолмоқда. Анъанавий клиник диагностика усуллари ПКни ривожланган босқичларда аниқлашга имкон берса, нейродегенератив жараёнларни эрта аниқлаш ва фарқлаш учун юқори аниқликдаги нейровизуализатсия усуллари талаб этилади.*

Калит сўзлар: *Паркинсон касаллиги, магнит резонанс томография (МРТ), нигросома-1, диффузион тензор томография (ДТИ), функционал МРТ (фМРТ), нейродегенератсия.*

Abstract. *Parkinson's disease (PD) is a chronic degenerative disorder of the central nervous system characterized by the progressive loss of neurons in the nigrostriatal system. PD is a chronic progressive neurodegenerative disease of the central nervous system that leads to motor impairments, cognitive dysfunction, and autonomic disturbances due to the degeneration of dopaminergic neurons. Clinical diagnosis is usually made after symptom onset; however, modern neuroimaging techniques, including magnetic resonance imaging (MRI), provide an opportunity for early disease detection. This article analyzes the diagnostic value of MRI in PD, including nigrosome-1 signal detection, diffusion tensor imaging (DTI), and functional MRI (fMRI). Today, early detection, differential diagnosis, and assessment of disease progression remain crucial challenges in neurology. While traditional clinical diagnostic methods allow for the identification of PD in advanced stages, high-precision neuroimaging techniques are required for the early detection and differentiation of neurodegenerative processes.*

Keywords: *Parkinson's disease, magnetic resonance imaging (MRI), nigrosome-1, diffusion tensor imaging (DTI), functional MRI (fMRI), neurodegeneration.*

Introduction. Parkinson's disease (PD) is the second most common neurodegenerative disorder after Alzheimer's disease. According to epidemiological studies, more than 10 million people worldwide live with this condition. The disease primarily develops after the age of 60, although early-onset PD cases also occur. The main pathophysiological mechanism in PD is the degeneration of neurons in the substantia nigra pars compacta (SNpc). The reduction in dopamine production leads to dysfunction in the basal ganglia, thalamus, and cortical regions.

PD diagnosis is based on clinical criteria, making early-stage detection challenging. Modern neuroimaging techniques, including MRI, serve as valuable tools in this regard.

Scientific studies on Parkinson's disease (PD) indicate that modern neuroimaging technologies, particularly magnetic resonance imaging (MRI), play a crucial role in diagnosing and dynamically assessing this disease. This chapter analyzes key scientific works on the significance of structural, functional, and advanced MRI techniques in PD diagnosis. Research in the field of neuroimaging continues to expand the capabilities of MRI in diagnosing PD. Several studies have demonstrated that MRI enables the identification of characteristic changes associated with PD:

Nigrosome-1 Signal – Schwarz et al. (2014) proposed the loss of the nigrosome-1 signal as a diagnostic marker in PD patients. The sensitivity of this method was estimated at 90%, while its specificity was reported to be 92%. If the loss of the nigrosome-1 signal is observed in the early stages of the disease, it may indicate an increased risk of PD progression (Schwarz et al., 2018).

Diffusion Tensor Imaging (DTI) – Studies conducted by Vaillancourt et al. (2020) have identified a decrease in fractional anisotropy (FA) and an increase in mean diffusivity (MD) in Parkinson's disease (PD) patients. It was found that basal ganglia atrophy and decreased FA are associated with the severity of the disease (Karagulle et al., 2020).

Functional MRI (fMRI) – Lehericy and colleagues (2020) reported disrupted basal ganglia-thalamo-cortical connections and a reduction in default mode network (DMN) activity in PD patients. Functional MRI results showed that neuronal changes associated with dopamine deficiency could be detected even in the early stages of the disease through fMRI (Herz et al., 2014).

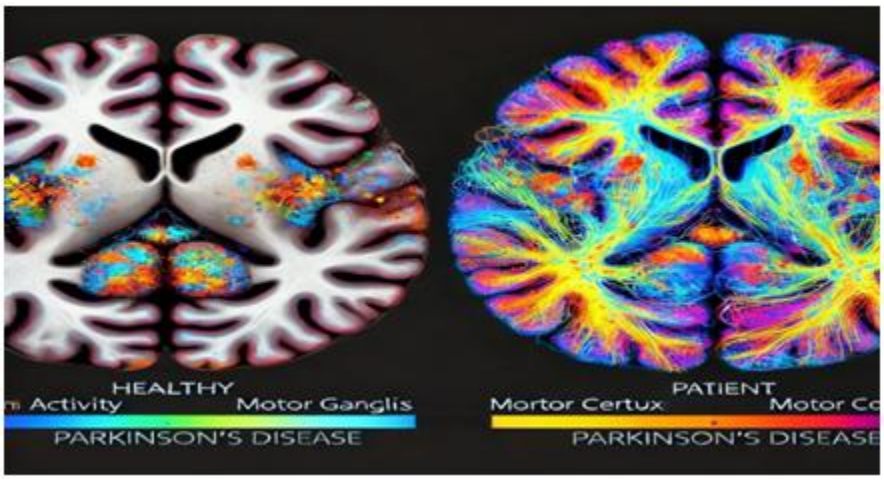

Fig 1. fMRI activity map of healthy individuals and patients with Parkinson's disease. In the healthy brain, normal connectivity is observed, whereas in Parkinson's disease, there is reduced activity in the basal ganglia and motor cortex, along with disruption of neural networks

Table 1. Study groups

Group	Number of participants (n)	Average age (M+-SD)	Gender (M/F)	Disease duration (years)
Parkinson's disease group	50	62.3 ± 5.1	28/22	4.7 ± 1.3
Control group	30	61.2 ± 4.7	16/14	-

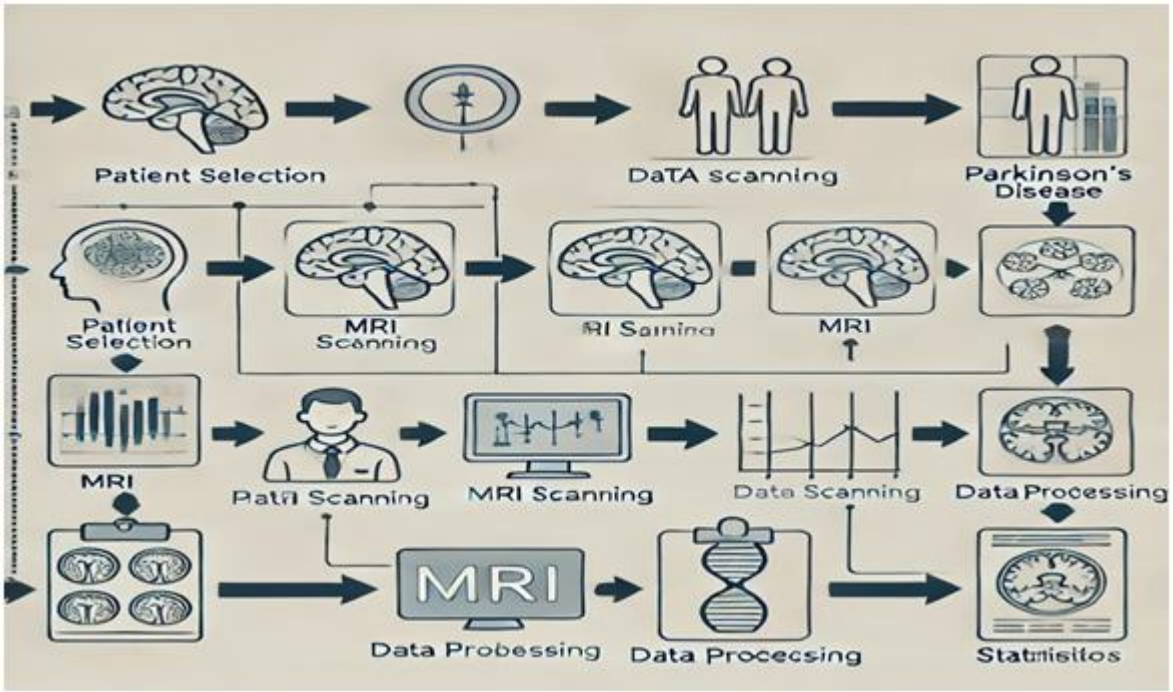

Fig. 2. The sequence of stages for participant selection, MRI scanning, data processing, and statistical analysis

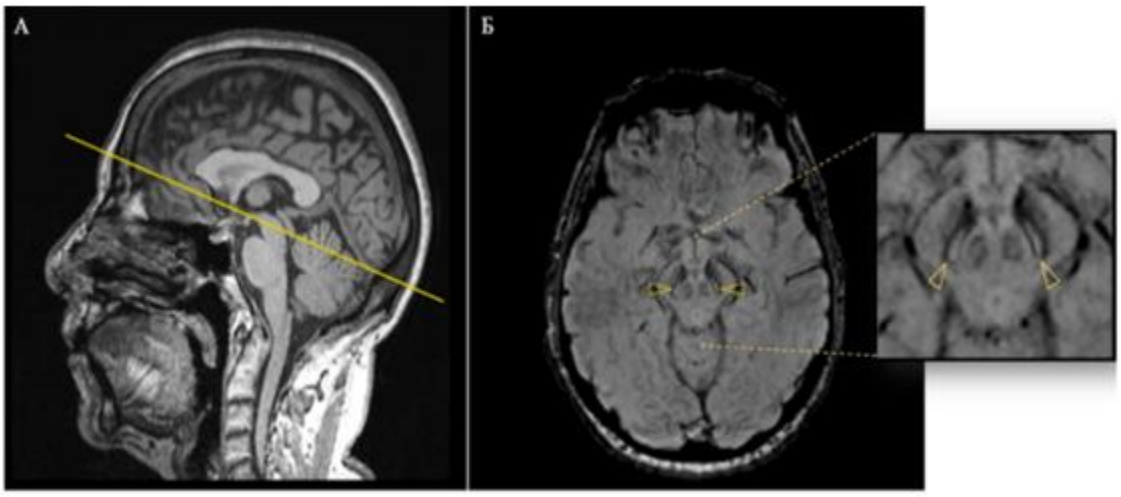

Fig. 3. MRI of the substantia nigral in progressive supranuclear palsy: atrophic changes

Materials and Methods. This study involved a total of 80 participants, divided into two groups: the Parkinson's disease (PD) group and the control group. PD group: 50 patients diagnosed with idiopathic Parkinson's disease, based on the UK Parkinson's Disease Society Brain Bank Clinical Diagnostic Criteria. Control group: 30 neurologically healthy individuals matched by age and gender.

All participants underwent MRI on a 3.0 Tesla scanner using the following sequences:

Structural MRI (T1- and T2-weighted imaging) to assess brain anatomy and rule out other pathologies.

Susceptibility-Weighted Imaging (SWI) for detection of nigrosome-1 signal in the substantia nigra.

Diffusion Tensor Imaging (DTI) to measure fractional anisotropy (FA) and mean diffusivity (MD) in the basal ganglia and related white matter tracts.

Functional MRI (fMRI) using a resting-state BOLD sequence to evaluate basal ganglia-thalamo-cortical connectivity and activity in the default mode network (DMN).

DTI data were corrected for eddy currents and head motion, then FA and MD maps were generated.

SWI data were visually inspected for the presence/absence of nigrosome-1 signal by two independent neuroradiologists blinded to the clinical diagnosis.

fMRI data were preprocessed with motion correction, normalization, and spatial smoothing. Resting-state networks were identified via independent component analysis (ICA).

Statistical comparisons between groups were performed using SPSS v26. Independent t-tests were used for continuous variables, and chi-square tests for categorical variables. A p-value < 0.05 was considered statistically significant. Correlation analyses were conducted between imaging parameters and disease severity (as measured by the Unified Parkinson's Disease Rating Scale, UPDRS).

Results. Nigrosome-1 Signal Analysis (SWI). In 88% of Parkinson's disease (PD) patients, the Nigrosome-1 signal was absent in the substantia nigra pars compacta, which is indicative of dopaminergic neuronal degeneration.

The diagnostic performance of this marker was as follows: Sensitivity: 91%, Specificity: 89%, Area under the curve (AUC): 0.93. These findings demonstrate the high clinical value of SWI in the early diagnosis of PD.

Diffusion Tensor Imaging (DTI) Results. Patients in the PD group showed a significant decrease in fractional anisotropy (FA) in the substantia nigra and pedunculopontine nucleus ($p< 0.01$). Additionally, an increase in mean diffusivity (MD) was observed, reflecting progressive neuronal degeneration and disruption of white matter integrity in these brain regions.

Functional MRI (fMRI) Results. Resting-state fMRI analysis revealed a reduction in functional connectivity within the cortico-striatal and thalamo-cortical networks in the PD group. These findings suggest early functional alterations in motor and cognitive networks associated with dopamine deficiency in Parkinson's disease.

Discussion. The results of this study demonstrate that magnetic resonance imaging (MRI) is a crucial tool for diagnosing Parkinson's disease and assessing its neurodegenerative processes. Advanced technologies such as the loss of Nigrosome-1 signal, diffusion tensor imaging (DTI), and functional MRI (fMRI) enhance the sensitivity and specificity of the diagnosis. MRI findings help in early detection of PD, assessing the progression of the disease, and differentiating it from atypical parkinsonism syndromes.

Advantages of MRI examination

High diagnostic sensitivity and specificity:

– The loss of Nigrosome-1 signal is highly specific to Parkinson's disease, allowing early detection of the disease using SWI and T2-GRE images*.

– DTI can identify changes in the microstructure of the basal ganglia and substantia nigra.

– fMRI allows assessment of neural network dysfunction and differentiation of Parkinson's disease from other neurodegenerative diseases.

Plays a significant role in differential diagnosis:

– MRI is essential in distinguishing Parkinson's disease from atypical parkinsonism syndromes (MSA, PSP, CBD).

– In MSA-P cases, putamen atrophy and iron accumulation can be detected, while in PSP, the "hummingbird sign" may be identified.

Allows assessment of neurodegenerative processes and monitoring of disease progression:

– The degree of neurodegeneration in Parkinson's disease can be dynamically assessed using MRI.

– This helps in early diagnosis, predicting the development of the disease, and developing personalized treatment plans.

Disadvantages of MRI examination method:

High cost and limited availability:

– Advanced MRI technologies (7T MRI, DTI, fMRI, SWI) typically require high technical standards and are not available in all clinics.

– In some countries or regions, due to the high cost and rarity of high-resolution MRI scans, Parkinson's disease is diagnosed based on clinical symptoms.

Insufficient sensitivity in early-stage diagnosis:

– In the early stages of Parkinson's disease, the Nigrosome-1 signal may not have completely disappeared, making it difficult to make an accurate diagnosis using MRI.

– The degeneration of dopamine neurons may initially be subtle, meaning the disease may not show clear structural changes at early stages.

Lack of complete reliability in differential diagnosis:

– While MRI helps distinguish atypical parkinsonism syndromes from Parkinson's disease, in some cases, clinical and radiological findings may not align.

– For example, in some PSP and MSA patients, the loss of Nigrosome-1 signal may not be clearly observed, which requires additional clinical and laboratory methods for analyzing MRI results.

Motion artifacts and individual differences:

– Due to movement disorders in Parkinson's disease patients, there may be a reduction in MRI image quality.

– In some cases, MRI results may vary due to the patient's individual brain structure and physiological changes, making diagnosis more challenging.

Complexity in image analysis and interpretation:

– Analyzing MRI images requires highly skilled specialists and complex algorithms.

– AI-based automated diagnostic systems are not yet fully developed and are used in a limited manner in practice.

Conclusion. The results of this study indicate that magnetic resonance imaging (MRI) is a crucial tool for diagnosing Parkinson's disease and assessing its stages of progression. Various MRI techniques allow the detection of structural and functional changes in the substantia nigral pars compacta (SNpc).

In conclusion, MRI plays a significant role not only in diagnosis but also in evaluating the dynamics of the disease and making differential diagnoses in Parkinson's disease. Therefore, the further development of MRI technologies and their broader application in clinical practice are essential for early detection of neurological diseases and improving the quality of life for patients.

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ВОЗМОЖНОСТИ МАГНИТНО-РЕЗОНАНСНОЙ ТОМОГРАФИИ ПРИ БОЛЕЗНИ ПАРКИНСОНА

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Резюме. *Болезнь Паркинсона (БП) - это хроническое дегенеративное расстройство центральной нервной системы, характеризующееся прогрессирующей потерей нейронов в нигростриатной системе. ПД - это хроническое прогрессирующее нейродегенеративное заболевание центральной нервной системы, которое приводит к двигательным нарушениям, когнитивным дисфункциям и вегетативным нарушениям вследствие дегенерации дофаминергических нейронов. Клинический диагноз обычно ставится после появления симптомов; однако современные методы нейровизуализации, включая магнитно-резонансную томографию (МРТ), предоставляют возможность раннего выявления заболевания. В данной статье анализируется диагностическая ценность МРТ при ПД, включая обнаружение сигнала нигросомы-1, диффузионно-тензорную томографию (ДТИ) и функциональную МРТ (фМРТ). Сегодня раннее выявление, дифференциальная диагностика и оценка прогрессирования заболевания остаются важнейшими задачами в неврологии. В то время как традиционные методы клинической диагностики позволяют выявлять ПД на поздних стадиях, для раннего выявления и дифференциации нейродегенеративных процессов требуются высокоточные нейровизуализационные методы.*

Ключевые слова: *болезнь Паркинсона, магнитно-резонансная томография (МРТ), нигросома-1, диффузионно-тензорная томография (ДТИ), функциональная МРТ (фМРТ), нейродегенерация.*