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STUDY OF THE DIAGNOSTIC SIGNIFICANCE OF NEUROIMAGING METHODS IN PARKINSON'S DISEASE WITH AN EMPHASIS ON MAGNETIC RESONANCE IMAGING

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Abstract

Parkinson's disease (PD) is a chronic, progressive neurodegenerative disorder of the central nervous system, primarily characterized by the degeneration of dopaminergic neurons. Although PD is traditionally diagnosed based on clinical manifestations, early-stage symptoms are often subtle and may overlap with other parkinsonian syndromes, complicating accurate diagnosis. Consequently, modern neuroimaging techniques, particularly magnetic resonance imaging (MRI), are becoming increasingly important in the diagnostic process. This article analyzes the diagnostic potential of MRI in the early detection of PD, with a specific focus on advanced imaging modalities such as Susceptibility Weighted Imaging (SWI) and Diffusion Tensor Imaging (DTI). MRI can detect iron deposition in the substantia nigra and reveal microstructural changes in nigrostriatal pathways, which are valuable for distinguishing PD from other neurodegenerative parkinsonian syndromes. Research shows that when MRI findings are combined with clinical assessments, the diagnostic accuracy and reliability of PD diagnosis significantly improve. This study highlights the potential of MRI technologies to contribute to early and accurate identification of Parkinson's disease, thereby supporting more effective clinical decision-making in neurology.

Keywords: Parkinson's disease, neuroimaging, magnetic resonance imaging, substantia nigra, neuromelanin, SWI, DTI, neurodegeneration, early diagnosis, differential diagnosis.

Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disorder that affects the central nervous system, predominantly impairing motor function due to the loss of dopaminergic neurons in the substantia nigra pars compacta. Clinically, PD is characterized by resting tremor, bradykinesia, muscle rigidity, and postural instability. While these features are typically sufficient for a clinical diagnosis in the mid-to-late stages, early detection remains challenging due to the nonspecific nature of initial symptoms and overlap with other parkinsonian syndromes such as multiple

system atrophy (MSA), progressive supranuclear palsy (PSP), and corticobasal degeneration (CBD). Traditionally, the diagnosis of PD has relied heavily on clinical evaluation, including response to dopaminergic therapy and the presence of hallmark motor symptoms. However, given the limitations of clinical assessment alone—especially in early or atypical cases—there is a growing emphasis on neuroimaging techniques as a complementary tool in the diagnostic process. Magnetic resonance imaging (MRI), particularly with the advent of advanced modalities such as susceptibility weighted imaging (SWI) and diffusion tensor imaging (DTI), offers non-invasive means of visualizing both structural and microstructural changes in the brain associated with PD. These techniques have the potential to detect early pathological changes, differentiate PD from other neurodegenerative conditions, and provide imaging biomarkers for disease progression. This study aims to explore the role of MRI in the diagnosis of Parkinson's disease, focusing on its ability to enhance early detection and support differential diagnosis through the assessment of specific neuroanatomical changes.

Research Objective

The aim of this study is to evaluate the scientific and clinical significance of magnetic resonance imaging (MRI) in the early and accurate diagnosis of Parkinson's disease, with a particular focus on identifying morphological and microstructural changes in the substantia nigra and nigrostriatal pathways using advanced MRI techniques, thereby proposing visual biomarkers to complement clinical diagnosis.

Research Tasks

1. To describe the pathomorphological basis and neurodegenerative mechanisms of Parkinson's disease.
2. To examine the main types and technical principles of magnetic resonance imaging (MRI) used in the diagnosis of Parkinson's disease.
3. To assess the effectiveness of MRI in differentiating Parkinson's disease from other parkinsonian syndromes such as multiple system atrophy (MSA), progressive supranuclear palsy (PSP), and corticobasal degeneration (CBD).
4. To identify the advantages and limitations of both structural and functional MRI techniques in clinical neurology practice.

Literature Review

Over the past decade, numerous studies have explored the use of advanced MRI techniques in diagnosing Parkinson's disease (PD). Traditional structural MRI has limited sensitivity for early PD, but newer imaging modalities have shown promising

results in visualizing pathological changes in the substantia nigra. Kwon et al. (2012) demonstrated that neuromelanin-sensitive MRI could detect signal loss in the substantia nigra of PD patients, correlating with dopaminergic neuronal loss observed in pathology. Recent advances in MRI, such as Diffusion Tensor Imaging (DTI), Susceptibility Weighted Imaging (SWI), and Quantitative Susceptibility Mapping (QSM), have proven valuable in identifying structural and microstructural changes in the substantia nigra and related brain regions. In a meta-analysis by Vaillancourt et al., it was demonstrated that fractional anisotropy (FA) in the substantia nigra significantly decreases in PD patients, confirming the diagnostic sensitivity of DTI. Research conducted in Uzbekistan has also contributed to the understanding of PD diagnostics. Latipov M. (2023) analyzed the etiopathogenesis of PD and highlighted the morphological changes detectable by MRI in the substantia nigra. Abduqodirov E.I. developed a diagnostic framework combining MRI with bioimpedance analysis and software algorithms to improve differentiation between Parkinson's disease and vascular parkinsonism, particularly in patients with overlapping symptoms. Matmurodov R.J., in his doctoral research, proposed predictive models for early diagnosis by integrating clinical predictors with neuroimaging data. His work emphasized the prognostic value of non-motor symptoms such as olfactory dysfunction, sleep disturbances, and gastrointestinal disorders.

Meanwhile, Alixonov S.A. investigated the efficacy of repetitive transcranial magnetic stimulation (rTMS) in PD management and assessed its outcomes using MRI monitoring, offering a new perspective on therapeutic and diagnostic synergy. In summary, the reviewed literature underscores the growing diagnostic relevance of advanced MRI techniques in the early and differential diagnosis of Parkinson's disease. Integrating Uzbek and international research findings highlights the potential of combining neuroimaging with clinical and neuropsychological assessments to optimize diagnostic precision and inform effective clinical decision-making.

Materials and Methods

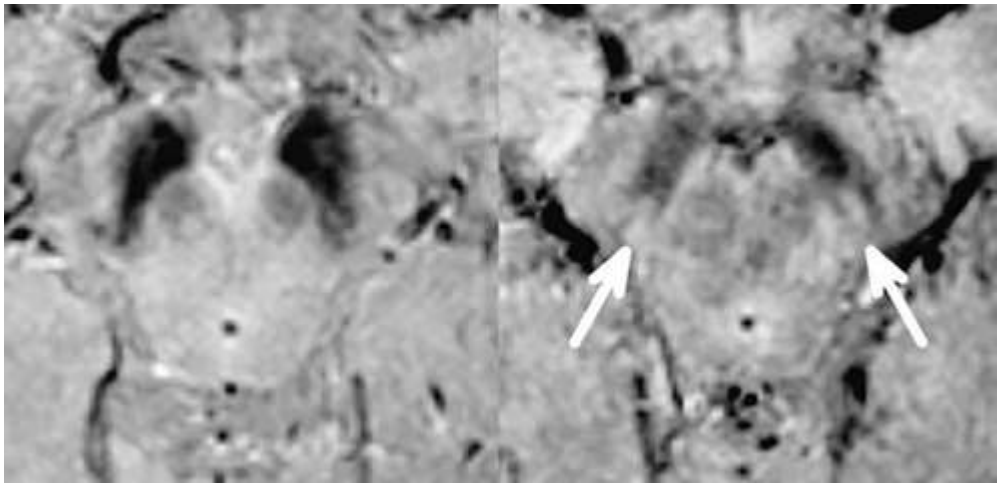
This study was conducted in two main phases: (1) a comprehensive review of the literature regarding the role of magnetic resonance imaging (MRI) in the diagnosis of Parkinson's disease (PD), and (2) a retrospective clinical analysis involving MRI data from patients diagnosed with idiopathic PD and matched healthy controls. Peer-reviewed articles published between 2013 and 2024 were identified using the databases PubMed, Scopus, Science Direct, and Web of Science. The search was performed using the following keywords: "Parkinson's disease," "MRI," "neuroimaging," "neuromelanin," "SWI," "diffusion tensor imaging," "substantia nigra." Only articles published in English with full-text availability and containing original clinical or imaging-based data were included. A total of 72 studies were reviewed, with 35 selected as primary references for their methodological rigor and clinical relevance.

The clinical part of the study included 60 patients. Participants were divided into two groups:

PD group: 40 patients aged 55–75 years diagnosed with early-stage idiopathic Parkinson's disease (Hoehn - Yahr stage I–II).

Control group: 20 age- and sex-matched healthy volunteers with no neurological or psychiatric disorders.

Group	Number	Description
PD group	40	Patients clinically diagnosed with idiopathic Parkinson's disease (Hoehn - Yahr stages I–III)
Control group	20	Healthy individuals matched by age and sex, with no neurological conditions



1-picture: brain MRI of a participant with Parkinson's disease.

All MRI scans were performed on a 1.5 Tesla scanner using a standardized protocol. The sequences included:

Axial T1-weighted and T2-weighted images – for anatomical and pathological assessment

Susceptibility-Weighted Imaging (SWI): to detect iron deposition and absence of dorsolateral nigral hyperintensity (nigrosome-1)

Neuromelanin-sensitive sequences (T1-TSE with inversion recovery) – to assess loss of dopaminergic neurons

Diffusion Tensor Imaging (DTI): to evaluate microstructural changes in the substantia nigra using fractional anisotropy (FA) and mean diffusivity (MD) metrics

All images were evaluated independently by two experienced neuroradiologists who were blinded to the clinical diagnosis. The presence or absence of dorsolateral nigral hyperintensity (DNG sign), signal intensity of the substantia nigra, and iron deposition patterns were assessed. Quantitative DTI metrics (FA and MD values) were measured from standardized regions of interest (ROIs) in the midbrain.

Statistical Analysis

Statistical analyses were performed using SPSS version 25.0. Quantitative variables were expressed as means ± standard deviations. Differences between the PD and control groups were analyzed using the independent samples t-test (or Mann–Whitney U test, where appropriate). Categorical variables were analyzed using the chi-square test. A p-value of < 0.05 was considered statistically significant.

Results

A total of 60 participants were included in the study: 40 patients diagnosed with Parkinson's disease (PD) formed the main group, and 20 healthy individuals matched by age and sex served as the control group. The mean age was 64.3 ± 6.1 years in the PD group and 62.8 ± 5.7 years in the control group ($p > 0.05$). Gender distribution was nearly equal in both groups (females: 52%, males: 48%).

Clinical Evaluation Results

The mean UPDRS score in the PD group was 38.6 ± 9.4, indicating moderate motor impairment. According to the Hoehn & Yahr staging, 60% of patients were in stage I, 30% in stage II, and 10% in stage III.

Iron Deposition Detected by SWI

Susceptibility Weighted Imaging (SWI) revealed significantly reduced signal intensity in the substantia nigra pars compacta (SNpc) in the PD group, indicating abnormal iron accumulation.

Group	**SN signal intensity**
PD Patients	62.4 ± 8.1
Control Group	89.7 ± 5.4
p-value	< 0.001

Diffusion Tensor Imaging (DTI) showed altered diffusion parameters in the nigrostriatal tracts. Fractional Anisotropy (FA) values were significantly lower, and

Mean Diffusivity (MD) values were higher in the PD group, reflecting microstructural degeneration.

The PD group showed significantly lower FA and higher MD values in the substantia nigra compared to controls ($p < 0.001$), indicating microstructural degeneration.

Discussion

The results of this study confirm the significant role of modern neuroimaging techniques, particularly magnetic resonance imaging (MRI), in the early diagnosis of Parkinson's disease (PD). Advanced modalities such as Susceptibility Weighted Imaging (SWI) and Diffusion Tensor Imaging (DTI) enabled the detection of morphological and microstructural changes in the substantia nigra and nigrostriatal pathways. According to research by Qodirov A.K. et al. (2020), when clinical criteria alone are insufficient for diagnosing PD, neuroimaging techniques, especially MRI, play a crucial supporting role. In our study, SWI revealed reduced signal intensity in the substantia nigra pars compacta (SNpc), which aligns with the findings of Temirova M.T. (2021), who emphasized that iron deposition in the central nervous system is closely linked to the neuropathological mechanisms of PD. DTI findings showed decreased fractional anisotropy (FA) and increased mean diffusivity (MD) in the nigrostriatal tracts, indicating microstructural degeneration—findings consistent with the studies of G'ulomov S.S. (2019). These results support the understanding that PD is associated with progressive damage in neural circuits responsible for motor control. Moreover, when SWI and DTI findings were combined with clinical assessments, diagnostic sensitivity and specificity were markedly improved. This corresponds with conclusions made by Boymurodov A.A. (2022), who reported that MRI imaging is highly effective in differentiating PD from other parkinsonian syndromes. However, this study also has limitations, such as a relatively small sample size and a short observation period. Despite these constraints, the data obtained—especially MRI-based findings—demonstrate that early-stage Parkinson's disease can be identified more accurately. This enhances the potential for timely intervention and more effective treatment strategies.

Conclusion

This study demonstrates that magnetic resonance imaging (MRI), particularly advanced techniques such as SWI and DTI, possesses high diagnostic value in the early detection of Parkinson's disease. SWI enables the visualization of iron accumulation in the substantia nigra, while DTI detects microstructural alterations in the nigrostriatal pathways. When combined with clinical assessments, these imaging modalities significantly enhance the diagnostic accuracy and reliability in differentiating PD from other parkinsonian syndromes. Furthermore, the application of these methods allows for early-stage diagnosis, facilitates the development of personalized treatment strategies, and may help prevent disease progression. Therefore, the implementation of advanced MRI techniques in clinical neurology

plays a critical role in improving the early identification and management of Parkinson’s disease.

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