

Parkinson's Disease and Neurotechnology: Emerging Surgical Approaches and Perspectives for the Next Decade

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Abstract

Introduction: Parkinson's disease (PD) is a progressive neurodegenerative disorder affecting motor and non-motor functions. In advanced or treatment-resistant cases, surgical strategies such as deep brain stimulation (DBS) and MR-guided focused ultrasound (MRgFUS) offer substantial symptomatic relief. With recent progress in neurotechnology, biomedical engineering, and molecular therapies, new surgical approaches are emerging. This narrative review explores the future of PD surgical treatment over the next 5 to 10 years, focusing on innovative and potentially disease-modifying strategies.

Method: A narrative literature review was conducted across PubMed, Scopus, and Embase, selecting recent clinical trials, systematic reviews, and experimental studies. Keywords used: "Parkinson's Disease", "DBS", "focused ultrasound", "gene therapy", "cell therapy", "brain-computer interface", "neurotechnology", "future perspectives". Articles were included based on relevance, innovation, and clinical applicability. Data were organized by thematic categories. No statistical analysis was applied.

Results: DBS remains the gold standard, reducing motor fluctuations and medication dependency. Its use in earlier disease stages is gaining support. MRgFUS provides a non-invasive lesioning option, though it is irreversible. Technological advances such as adaptive DBS, directional leads, cortical recordings (ECoG), and multi-target stimulation increase therapeutic precision. 7-Tesla MRI and tractography enable stimulation of symptom-specific networks. BCIs and spinal neuroprostheses are under investigation for gait restoration and freezing control. In biological domains, gene therapies using viral vectors (AAV-GDNF, AADC, GAD) show neuroprotective effects. Optogenetics and chemogenetics (DREADD) allow remote control of neural circuits. iPSC-based cell therapies have demonstrated safety in early-phase trials. Gene correction (e.g., GBA1, LRRK2) and anti alpha-synuclein antibodies represent promising future strategies.

Discussion: The field is shifting from symptomatic treatment

to personalized, disease-modifying neurosurgical approaches. Integration of neuromodulation with biotechnology may alter disease trajectory. Adaptive DBS and multitarget designs optimize stimulation, while gene and cell therapies offer restoration of affected networks. However, high costs, device complexity, safety concerns, and ethical issues in placebo-controlled trials remain obstacles.

Conclusions: Over the next 5 to 10 years, surgical care in PD is expected to evolve into a multimodal and individualized model, combining neurostimulation, biological therapies, and digital interfaces. These strategies aim not only to manage symptoms, but also to slow or modify disease progression, improving long-term autonomy and quality of life.

References

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