ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 12| Issue: 1| January2026|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2025: 8.691 || ISI Value: 1.188

IMPACT OF GUT-BRAIN-AXIS MODULATION IN PARKINSON'S DISEASE –A LITERATURE REVIEW

Kathal Sab H[1], Shahida Jalaluddin Khan[2], Lavanya Amrutha R[3], Akanksha Vilas Gadkari[4]
Gardern City University, School of Health Sciences, Department of Physiotherapy

Article DOI: https://doi.org/10.36713/epra25604
DOI No: 10.36713/epra25604

ABSTRACT

Parkinsonism represents a spectrum of neuro-degenerative disorders hallmarked by progressive motor symptoms, with a growing recognition of diverse non-motor manifestations that significantly affects quality of life. The understanding of Parkinson's disease is changing, with growing evidence showing that the gut-brain-axis is the communication link between the gut, brain, immune system, and gut microbes and plays an important role in how the disease starts and develops.This literature review systematically evaluates research published post-2020, focusing on mechanistic insights, clinical significance, and therapeutic possibilities of gut–brain axis modulation in parkinsonism. Database searches across PubMed and Google Scholar yielded 70 articles, with 29 English-language, full-text studies selected, emphasizing relevance to gut microbiota, intestinal barrier dysfunction, neuro-inflammatory mechanisms, and interventions targeting the GBA.Key findings highlight that early gastrointestinal dysfunction Precedes by many years before the classical motor symptoms appear in Parkinsonism. Accumulation of misfolded alpha-synuclein in enteric neurons supports the Braak's hypothesis of peripheral origin and vagus nerve-mediated propagation to the brain, supported by the detection of Lewy pathology in gut tissues and experimental evidence from animal models. The "leaky gut" phenomenon is shown to trigger systemic and neuroinflammation, further facilitating alpha-syn aggregation and neuro-degeneration. Dysbiosis is consistently observed in many studies, marked by reduced diversity and diminished populations of SCFA producing bacteria (Prevotella, Faecalibacterium, Roseburia) with corresponding expansion of pro-inflammatory taxa (Akkermansia, Lactobacillus, Enterococcus, Desulfovibrio). Environmental and lifestyle factors – including Western dietary patterns, infections, pesticides, and chronic stress – contribute to the worsening of microbiota profiles and gut barrier function, whereas adoption of Mediterranean or vegetarian diets improvesmicrobial diversity and could decrease disease risk or progression. "Body-first" and "brain-first" pathophysiological subtypes of PD are found to differentiate cases where alpha-synuclein pathology either starts peripherally and spreads centrally or originates in the brain itself, indicating tailored clinical approaches required.Therapeutically, advances in probiotics, prebiotics, fiber-rich dietary strategies, FMT, and innovative pharmacological or neuromodulatory interventions (including GLP-1 agonists, nutraceuticals, and vagus nerve stimulation) offer promising results but still need further research to increase efficacy .

Despite exciting progress, several limitations constrain the field: the absence of definitive causal relationships, substantial inter-individual microbiome variability, and short-term, small-scale clinical studies. Biomarker development and clinical translation are hindered by population heterogeneity and methodological inconsistencies. Future research must focus on longitudinal designs tracking microbiota dynamics from early stages, mechanistic clarity of bidirectional GBA signaling, and combination therapies that combine lifestyle, dietary, and advanced medical approaches for optimized patient outcomes.

KEYWORDS USED - *Parkinsonism,Gut-Brain Axis,Impact of Gut-Brain-Axis in Parkinsonism, Relationship Between Gut-Brain-Axis in Parkinsonism, Therapeutic Options in Gut-Brain Axis Modulation,Gut to Brain Axis Modulation in Parkinsonism*

INTRODUCTION

Parkinsonism encompasses a group of neuro-degenerative disorders characterized primarily by motor symptoms such as bradykinesia, rigidity, and tremors, alongside a range of non-motor symptoms that significantly affect patient quality of life [(1)]. Parkinsonism, pathologically involves the misfolding and aggregation of alpha-synuclein protein (α-syn) leading to dopaminergic neuro-degeneration in the substantia nigra and other brain regions (Patrick James Oliver et al).Recent years have witnessed growing evidence suggesting the gut-brain axis (GBA)—a bidirectional communication network integrating the central nervous system, enteric nervous system, immune system, and gut microbiome in the pathogenesis and progression of parkinson's disease . Gastrointestinal dysfunction is often found to precede the motor symptoms by years.[(2)]This supports the hypothesis that pathological α-syn aggregation may initiate in the enteric nervous system and propagate to the brain via the vagus nerve and other pathways .[(1)(3)] Moreover, gut microbiota dysbiosis has been associated with increased intestinal permeability, neuroinflammation, and α-syn accumulation, suggesting that gut health directly influences neurodegenerative processes in PD.[(4)(5)] These findings have spurred interest in therapeutic strategies targeting the GBA, including probiotics, dietary modulation, fecal microbiota transplantation, and vagus nerve stimulation, aiming to modify disease progression and symptomatology . Despite growing knowledge, critical gaps remain regarding the

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 12| Issue: 1| January2026|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2025: 8.691 || ISI Value: 1.188

mechanisms linking gut dysfunction to PD and the efficacy of gut-targeted interventions.

Aim/Objective of the study

This literature review aims to critically evaluate and synthesize recent research (post-2020) on the impact of the gut-brain axis in parkinsonism, focusing on its pathophysiological role and potential therapeutic options. Utilizing studies sourced from Google Scholar and PubMed, this review explores the relationship between gut microbiota alterations, intestinal barrier integrity, α-syn propagation, and neuroinflammation in parkinsonism. It further examines emerging gut-brain axis modulation therapies and discusses their clinical relevance and translational potential for improving patient outcomes.

Methodology

This literature review was undertaken to qualitatively investigate the impact of the gut–brain axis on parkinsonism also focusing on the underlying pathophysiological mechanisms and therapeutic strategies involving modulation of the gut–brain axis. The review aimed to collect the emerging evidence regarding gut microbiota alterations, neuro-inflammatory pathways, intestinal permeability, in relation to Parkinson's disease and related parkinsonian syndromes.

Search Strategy

A comprehensive search was performed across electronic databases including PubMed and Google Scholar to identify relevant peer-reviewed publications. A combination of predefined keywords was used for maximum retrieval of eligible articles. The keywords included are : "Parkinsonism," "Gut–brain axis," "Impact of gut–brain axis in parkinsonism," "Relationship between gut–brain axis in parkinsonism," "Therapeutic options in gut–brain axis modulation," and "Gut to brain axis modulation in parkinsonism." Additional cross-referencing of bibliographies from selected studies was conducted to ensure inclusion of relevant literature not initially captured in the database search.

Inclusion Criteria

Studies published in English language only.
Studies published from 2020 onwards, in order to focus on the most current evidence and updated information.
Studies published in English language only
Full-text availability of the articles for detailed qualitative data extraction.
Articles examining mechanistic links between gut dysfunction and Parkinson's pathology, such as gut dysbiosis, microbial metabolites, intestinal barrier function, neuroinflammation.
Studies examining therapeutic interventions modulating the gut–brain axis, such as probiotics, prebiotics, dietary modulation, antibiotics, latest interventions.

Exclusion Criteria

Non-English publications.
Articles older than 2020.
Studies investigating parkinsonism not in the context related to gut–brain axis mechanisms (e.g., articles focusing exclusively on genetic mutations or environmental toxins without microbiota involvement).

Study Selection and Screening

The initial database search yielded 70 articles. After removal of duplicates and application of screening criteria based on titles and abstracts, 45 articles remained. A full-text review of these articles was subsequently conducted, following the inclusion and exclusion criteria. Finally, 28 publications were selected and included in this review. A data extraction sheet was systematically used to capture study design, population/model characteristics, principal findings, and therapeutic implications

Major Findings

Parkinson's disease (PD) shows strong involvement of the gut-brain axis, where gut microbiota disturbances, intestinal dysfunction, and alpha-synuclein pathology interact to drive both motor and non-motor symptoms. Hence , the major findings of our study can be discussed under various topics such as-

Alpha-Synuclein Pathology and Gut Origin

Chen SJ et.al and Klann EM et.al ,state in their studies that Alpha-synuclein aggregation in the gastrointestinal tract is considered an early event in Parkinson's disease, with Lewy body pathology detected in enteric neurons long before the onset of motor symptoms. The Research supports Braak's hypothesis that misfolded alpha-synuclein can spread from the gut to the brain via the vagus nerve, while alternative non-vagal routes such as sympathetic nerves, circulation, and immune pathways also play a role. The appendix has been identified as a major site of alpha-synuclein deposition, linking gut immune activity to Parkinson's disease risk. Misfolded alpha-synuclein not only propagates in a prion-like fashion but also triggers chronic inflammation and gut barrier dysfunction, mechanisms that may contribute to systemic neurodegeneration and highlight the significance of the gut-brain axis in Parkinson's disease pathogenesis.[(1)(6)] ENS involvement explains why gastrointestinal (GI) symptoms (constipation, bloating, delayed gastric emptying, SIBO) often precede motor symptoms by decades.[(2)]

Gut Barrier Dysfunction and Inflammation

Gushi S et al describes "leaky gut" as increased intestinal permeability observed in patients with Parkinson's disease (PD), which allows bacterial endotoxins like lipopolysaccharide (LPS) and other toxins to enter the bloodstream,triggering systemic and neuro inflammation. This permeability results from gut dysbiosis, where beneficial bacteria that maintain the gut barrier, such as Prevotellaceae and Lactobacillus, are reduced, while pro-inflammatory bacteria increase. The compromised gut barrier facilitates systemic inflammation and neuroinflammation via the gut-brain axis, contributing to α-synuclein misfolding and aggregation, neurodegeneration, and the progression of PD symptoms.[(5)(7)(8)] Also, Caradonna E et al state in their study that shared genetic risk loci exist between PD and inflammatory bowel disease (e.g., LRRK2, SNCA mutations), indicating overlapping gut-immune susceptibility.[(9)]

Gut Microbiota Dysbiosis Features

Several studies have found a decrease in SCFA(Short Chain Fatty Acid) levels, due to decrease in SCFA producing bacterias

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 12| Issue: 1| January2026|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2025: 8.691 || ISI Value: 1.188

and increase in pro-inflammatoy bacterias. Reduced short-chain fatty acid (SCFA)-producing bacteria are seen which include:Prevotella, Roseburia, Faecalibacterium, Lachnospiraceae,Blautia.Increased pro inflammatory/pathogenic bacterias are found such as : Akkermansia,Lactobacillus,Bifidobacterium, Enterobacteriaceae, Megasphaera, Desulfovibrio, Streptococcus.[2][6][8]
SCFA reduction worsens barrier integrity and inflammation, while some bacteria (Enterococcus, Lactobacillus) degrade levodopa, reducing treatment efficacy.[2]

Microbial Metabolite Alterations
Reduced beneficial metabolites such as "SCFAs, anti-inflammatory bile acids, and neurotrophic compounds" and increased harmful metabolites such as "trimethylamine N-oxide (TMAO), LPS, pro-inflammatory bile acids" are observed.[10]

Environmental and Lifestyle Factors
Triggers include pesticide exposure, heavy metals, GI infections, chronic stress, and aging.[2][11]
Western diet (high-fat, processed) worsens dysbiosis, while Mediterranean/vegetarian diets promote microbial diversity and reduce risk.[7][10][12][13]
Exercise may indirectly improve microbiota composition, increasing dopamine availability and neuroprotection.[14]

PD Clinical Subtypes: Brain-First vs. Body-First-
Menozzi E et al, discuss two distinct pathological subtypes of Parkinson's disease (PD): "body-first" and "brain-first." In the body-first subtype, the pathological process, including alpha-synuclein aggregation, initiates in the peripheral autonomic nervous system, particularly the gut, and then spreads to the brain via the vagus nerve. This subtype is characterized by early autonomic symptoms such as constipation before the onset of motor symptoms. In contrast, the brain-first subtype begins with neurodegeneration in the brain, particularly in the substantia nigra or other central nervous system regions, with less prominent early involvement of the peripheral autonomic nervous system. This subtype presents primarily with motor symptoms before significant autonomic dysfunction. Understanding these subtypes highlights the heterogeneity in PD pathogenesis and suggests that tailored diagnostic and therapeutic strategies are needed for each subtype.[15]

Therapeutic Interventions
Dietary interventions: Mediterranean, ketogenic, low-protein diets improve gut health and may modify PD progression.[13][16]
Probiotics/Prebiotics are Shown to improve constipation, reduce inflammation, and restore microbial balance; though limited but promising motor/cognitive benefits are seen.[17][18]

Early studies done on Fecal Microbiota Transplantation (FMT) indicate safety and potential benefits for both GI and motor symptoms, though results are mixed and short-term.[16][19][20][21]

Pharmacological modulation: Prokinetics (like domperidone), GLP-1 agonists, and nutraceuticals (curcumin, resveratrol, catechins) attenuate gut-related inflammation and show neuroprotective effects. [6][14]
Microbiome-drug interactions: PD medications (levodopa, COMT inhibitors) themselves alter gut microbiota, influencing therapy outcomes.[4]
Emerging strategies such as Postbiotics, bacteriophages, CRISPR-based microbiome editing, and neuromodulation (vagus nerve stimulation, VR rehabilitation) have shown some impact ,but are still under study.[3][20]

Ssummaryy of the Major Findings

Article Title	Authors	Method	Major findings
The gut-brain axis and its relation to Parkinson's disease : A Review	Klann EM et.al(2022)	Narrative Review	Gut dysbiosis contributes to neuro-inflammation and alpha synuclein pathology in PD
The role of the microbiota-gut-brain axis and intestinal microbiome dysregulation in Parkinson's disease	Li Q et al (2023)	Systematic review	Microbial imblance and SCFA alterations drive PD progression and offer therapeutic targets
Gut-brain Axis Modulation in Remote Rehabilitation of Parkinson's Disease	Jin Y et al (2025)	Experimental study	Rehabilitation improved gut metabolome and nigral connectivity, supporting neuroprotective effects
Parkinson's disease and the gut microbiota connection	Yadav S Raj RG(2025)	Critical review	Dysbiosis implicated in PD; Microbiome modulation is a potential therapy
Role of the microbiome in the development of Parkinson's disease	Gushi S,Derdas SP (2025)	Scoping review	Microbial toxins and dysbiosis contribute contribute to PD pathophysiology
Gut microenvironmental changes as a potential trigger in Parkinson's disease	Chen SJ , Lin CH (2022)	Mechanistic review	Intestinal inflammation and permeability may initiate PD pathology
Are we what we eat ? Impact of diet on the gut-brain axis in Parkinson's disease	Alfonseti M et al (2022)	Narrative review	Mediterranean and fiber rich diets support protective microbiota diversity in PD

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 12| Issue: 1| January2026|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2025: 8.691 || ISI Value: 1.188

Update to the treatment of parkinson's disease based on the gut-brain axis mechanism	Sun X et al (2022)	Narrative review	Probiotics , Prebiotics , and FMT are promising PD interventions
The brain-gut-axis in Alzheimer and Parkinson disease : A Narrative review	Caradonna E et al (2024)	Narrative review	Dysbiosis in common in PD and AD , linking gut-brain pathways to neurodegeneration
The role of gut dysbiosis in Parkinson's disease mechanistic insights and therapeutic options	Wang W et al (2021)	Narrative review	Dysbiosis drives neuroinflammation , mitochondiral dysfunction and synuclein pathology
Parkinson's disease and the metal microbiome-gut-brain axis	Forero Rodriguez LJ et al(2021)	Literature review	Metals disrupt microbiota, enhancing oxidative stress and PD progression
Role of the gut brain axis microbial composition diet ad probiotic intervention in Parkinson's disease	Thangleela S et al(2022)	Narrative review	Diet and probiotics beneficially modulate the microbiota in PD
Microbiome-based therapies for parkinson's disease	Alam M et al (2024)	Narrative review	Probiotics , synbiotics, and FMT show therapeutic potential in PD
Rethinnking Parkinson's disease: gut brain interactions and exercise	Zapanta K et al (2022)	Narrative Review	Exercise improves gut microbiota and may slow PD progression
The gut-brain axis and Parkinson's disease : clinical and pathogenetics relevance	Menozzi E et al (2021)	Clinical review	Early gut dysfunction supports "body first " PD subtype
The role of microbiota dysbiosis in Parkinson's disease	Santos S et al (2025)	Narrative review	Dysbiosis promotes neurodegeneration and represents a therapeutic target
How microbes affect depressionn: mechanisms Via the gut brain axis	Suda K , Matsuda K (2022) mechanistic review	Narrative Review	Gut brain signalling affects mood, immunity and neurotransmission, relevant to PD
The gut-brain axis in early Parkinson's disease : From prodrome to prevention	Oliver PJ et al (2025)	Clinical review	Gut dysbiosis is a potential early biomarker in prodromal PD
Research progress of microbiota-gut-brain axis in Parkinson's disease	Zhang W et al (2023)	Narrative review	SCFA deficienncy and gut inflammation linked to PD mechanisms
Microbiome based therapuetic for Parkinson's disease	Hamilton AM et al (2024)	Narrative review	FMT and probiotics show promise but need larger clinical trials
Faecal microbiota transplant in Parkinson's disease : Pilot study	De Sciscio M et al(2025)	Clinical trial	FMT demonstrated safety and tolerability in PD patients
Gut microbiota and Parkinson's disease	Wang L et al (2025)	Narrative review	Altered gut bacteria may serve as PD Biomarkers and therapeutic targets
Guut -microbiome-brain axis : Vagus nerve ,alpha synuclein and the brain	Dos Santos JC et al (2023)	Mechanistic review	Vagal pathway may mediate aplha-synuclein transmission gut-to-brain
Microbiota-gut-brain axis and its therapeutic applications in neurodegenerative disease	Loh JS et al (2024)	Translational review	Microbiota manipulation applicable in PD and related disorders
The interplay between gut microbiota and the brain-gut axis in Parkinson's disease	Jia X et al (2024)	Narrative review	Probiotics, diet and FMT highlighted as adjunctive therapies
Curcumin inhibition of intestinal inflammation in PD	Zhong L et al(2022)	Experimental pharmacological study	Curcumin reduced gut inflammation and exerted neuroprotective effects
How leaky is the gut in Parkinson's disease ?	Derkinderen P et al(2025)	Clinical study	PD patients show increased intestinal permeability , supporting "Gut-first" hypothesis

DISCUSSION

Altered gut microbiota composition is one of the major findings in Parkinson's disease (PD) research. Multiple studies consistently report reduced abundance of genera such as Prevotella and Faecalibacterium, alongside increased Akkermansia, Lactobacillus, and Enterococcus species in PD patients compared to controls.[2][5][10][22] This dysbiosis is linked with decreased microbial diversity, which may impair gut

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 12| Issue: 1| January2026|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2025: 8.691 || ISI Value: 1.188

barrier function and promote systemic inflammation.[7][19] More Importantly , it is observed that GI symptoms like constipation precede classical motor features by years, highlighting the gut as an early contributor or indicator of disease[6][14][18]. Thus, dysbiosis may represent both a pathological driver and biomarker for parkinsonism.

Increased gut permeability or "leaky gut" has been documented in PD, marked by elevated fecal calprotectin and diminished expression of tight junction proteins such as zonulin, occludin, and ZO-1 in colonic biopsies (Pascal Derkinderen et al). This breakdown allows translocation of microbial products like lipopolysaccharide (LPS), which can trigger systemic and neuroinflammation by activating immune pathways and cytokine release.[5][10]

Experimental models confirm that LPS promotes alpha-synuclein aggregation and neurodegeneration.[6] The resulting inflammatory cascade may potentiate neuronal vulnerability, aligning with the hypothesis that gut barrier dysfunction propagates central pathology.The presence of misfolded alpha-synuclein in the enteric nervous system supports Braak's hypothesis of a gut origin for PD pathology, with pathogenic forms ascending via the vagus nerve to the brainstem.[6][23]Animal studies demonstrating retrograde alpha-synuclein transport and prevention of propagation by vagotomy provide mechanistic evidence. [6][22][23]However, this theory is not universally accepted. Autopsy series fail to identify Lewy pathology in the gut without concurrent brain involvement, suggesting heterogeneity in disease initiation.[2][18] This implies possible PD subtypes with different pathogenic pathways where the gut may act as either an initiating site or secondary amplifier.

Dysbiosis and gut permeability promote peripheral immune activation, evidenced by elevated TNF-α, IL-1β, and IL-6 in PD patients correlating with disease severity.[9][16][24] Genetic factors such as PINK1 mutations may amplify sensitivity to mitochondrial antigens during intestinal inflammation, exacerbating dopaminergic neuron loss.[3][4][11]Together, dysregulated immune responses link microbiota alterations to neurodegeneration.

Probiotics and Prebiotics used in early clinical trials as therapeutic options suggest probiotics can alleviate GI symptoms and mildly improve motor function, possibly via modulation of oxidative stress and inflammation.[8][12]Fecal Microbiota Transplantation (FMT) Pilot studies establish FMT safety and potential to restore SCFA profiles and brain connectivity in PD, but larger randomized controlled trials are necessary .[13][20][24]Mediterranean-type diets rich in fiber and polyphenols promote microbial diversity and reduce inflammation, contrasting the detrimental effects of Western diets on gut composition and PD risk.[2][7][10][12][13][19]

Pharmacological Influences:Gut bacteria can metabolize levodopa, impacting its efficacy, and antibiotics such as minocycline show neuroprotective effects partially by altering gut–brain pathways.[2][15]

Limitations and future directions of the study

Despite advances in therapeutic application of GBA axis in parkinsonism, challenges still remain. The causal relationship between dysbiosis and PD is not definitively established; altered microbiota may result from lifestyle, medication, or disease progression rather than cause it. Microbial signatures vary between individuals and studies, complicating biomarker development . [9][22]

Braak's staging, while influential, may not apply universally due to PD heterogeneity (Zhang et al). Clinical studies are often limited by small cohorts, heterogenous interventions, and short follow-up, limiting generalizability.

Longitudinal studies are required to track microbiota dynamics from prodromal to advanced PD stages and clarify causal pathways. Integrative approaches combining microbiota-targeted therapies with exercise and dietary interventions may optimize neuroprotection and symptom control.

CONCLUSION

The research indicates that the **gut–brain axis** has a strong connection to Parkinson's disease, with the gut and brain influencing each other in multiple ways. Scientists have found that disturbances in gut bacteria, a weakened intestinal barrier, and persistent inflammation may all play a role in triggering and worsening the disease. Patients with Parkinson's often experience gastrointestinal problems, such as constipation, long before motor symptoms appear. Researchers have also observed that abnormal alpha-synuclein proteins can accumulate in the gut prior to being detected in the brain, which supports the theory that Parkinson's may begin in the body and later spread centrally. Microbiome studies show that patients typically have fewer protective bacteria that produce short-chain fatty acids and more harmful bacteria that increase inflammation. These imbalances not only damage the intestinal lining and promote neuroinflammation but also interfere with how Parkinson's medications are absorbed and work in the body. In response to these findings, researchers are testing new treatment strategies that focus on improving gut health. These include the use of probiotics, prebiotics, tailored diets, fecal microbiota transplants, and advanced drug therapies. While the early results appear promising, existing studies are small, varied in quality, and do not yet prove a direct cause-and-effect relationship. Larger, long-term studies should be designed to clarify whether gut changes directly contribute to Parkinson's, to better understand the underlying biological mechanisms, and to test combined therapeutic approaches.

REFERENCES

1. *Klann EM, Dissanayake U, Gurrala A, Farrer M, Shukla AW, Ramirez-Zamora A, Mai V, Vedam-Mai V. The gut–brain axis and its relation to Parkinson's disease: a review. Frontiers in aging neuroscience. 2022 Jan 7;13:782082.*
2. *Li Q, Meng LB, Chen LJ, Shi X, Tu L, Zhou Q, Yu JL, Liao X, Zeng Y, Yuan QY. The role of the microbiota-gut-brain axis and intestinal microbiome dysregulation in Parkinson's disease. Frontiers in Neurology. 2023 May 25;14:1185375.*
3. *Jin Y, Wang H, Song J. Gut-Brain Axis Modulation in Remote Rehabilitation of Parkinson's Disease: Reconstructing the*

Fecal Metabolome and Nigral Network Connectivity. Frontiers in Neurology. 2025 Aug 15;16:1644490.

4. *Yadav S, Raj RG. Parkinson's disease and the gut microbiota connection: unveiling dysbiosis and exploring therapeutic horizons. Neuroscience. 2025 Jul 2.*
5. *Gushi S, Derdas SP. Role of the microbiome in the development of Parkinson's disease. World Academy of Sciences Journal. 2025 Jul 14;7(5):86.*
6. *Chen SJ, Lin CH. Gut microenvironmental changes as a potential trigger in Parkinson's disease through the gut–brain axis. Journal of Biomedical Science. 2022 Jul 27;29(1):54.*
7. *Alfonsetti M, Castelli V, d'Angelo M. Are we what we eat? impact of diet on the gut–brain axis in Parkinson's disease. Nutrients. 2022 Jan 17;14(2):380.*
8. *Sun X, Xue L, Wang Z, Xie A. Update to the treatment of Parkinson's disease based on the gut-brain axis mechanism. Frontiers in neuroscience. 2022 Jul 6;16:878239.*
9. *Caradonna E, Nemni R, Bifone A, Gandolfo P, Costantino L, Giordano L, Mormone E, Macula A, Cuomo M, Difruscolo R, Vanoli C. The brain–gut axis, an important player in Alzheimer and Parkinson disease: a narrative review. Journal of Clinical Medicine. 2024 Jul 15;13(14):4130.*
10. *Wang Q, Luo Y, Ray Chaudhuri K, Reynolds R, Tan EK, Pettersson S. The role of gut dysbiosis in Parkinson's disease: mechanistic insights and therapeutic options. Brain. 2021 Sep 1;144(9):2571-93.*
11. *Forero-Rodríguez LJ, Josephs-Spaulding J, Flor S, Pinzón A, Kaleta C. Parkinson's disease and the metal–microbiome–gut–brain axis: a systems toxicology approach. Antioxidants. 2021 Dec 28;11(1):71.*
12. *Thangaleela S, Sivamaruthi BS, Kesika P, Bharathi M, Chaiyasut C. Role of the gut–brain axis, gut microbial composition, diet, and probiotic intervention in Parkinson's disease. Microorganisms. 2022 Jul 29;10(8):1544.*
13. *Alam M, Abbas K, Mustafa M, Usmani N, Habib S. Microbiome-based therapies for Parkinson's disease. Frontiers in Nutrition. 2024 Nov 6;11:1496616.*
14. *Zapanta K, Schroeder ET, Fisher BE. Rethinking Parkinson disease: exploring gut-brain interactions and the potential role of exercise. Physical Therapy. 2022 May 1;102(5):pzac022.*
15. *Menozzi E, Macnaughtan J, Schapira AH. The gut-brain axis and Parkinson disease: clinical and pathogenetic relevance. Annals of Medicine. 2021 Jan 1;53(1):611-25.*
16. *Santos S, Salinas I, Almeida N, Caicedo A. The role of microbiota dysbiosis in Parkinson's disease: Pathophysiology and therapeutic opportunities. Engineering Microbiology. 2025 Jun 28:100222.*
17. *Suda K, Matsuda K. How microbes affect depression: underlying mechanisms via the Gut–brain axis and the modulating role of probiotics. International journal of molecular sciences. 2022 Jan 21;23(3):1172.*
18. *Oliver PJ, Civitelli L, Hu MT. The gut–brain axis in early Parkinson's disease: from prodrome to prevention. Journal of Neurology. 2025 Jun;272(6):413.*
19. *Zhang W, Ye Y, Song J, Sang T, Xia T, Xie L, Qiu X, Zeng Q, Luo X. Research progress of microbiota-gut-brain axis in parkinson's disease. Journal of integrative neuroscience. 2023 Oct 30;22(6):157.*
20. *Hamilton AM, Krout IN, White AC, Sampson TR. Microbiome-based therapeutics for Parkinson's disease. Neurotherapeutics. 2024 Oct 1;21(6):e00462.*
21. *De Sciscio M, Bryant RV, Haylock-Jacobs S, Day AS, Pitchers W, Iansek R, Costello SP, Kimber TE. Faecal microbiota transplant in Parkinson's disease: pilot study to establish safety & tolerability. npj Parkinson's Disease. 2025 Jul 9;11(1):203.*
22. *Wang L, Cui Y, Han B, Du Y, Salewala KS, Wang S, Zhao W, Zhang H, Wang S, Xu X, Ma J. Gut microbiota and Parkinson's disease. Chinese medical journal. 2025 Feb 5;138(03):289-97.*
23. *Dos Santos JC, Oliveira LF, Noleto FM, Gusmão CT, de Castro Brito GA, de Barros Viana GS. Gut-microbiome-brain axis: the crosstalk between the vagus nerve, alpha-synuclein and the brain in Parkinson's disease. Neural regeneration research. 2023 Dec 1;18(12):2611-4.*
24. *Loh JS, Mak WQ, Tan LK, Ng CX, Chan HH, Yeow SH, Foo JB, Ong YS, How CW, Khaw KY. Microbiota–gut–brain axis and its therapeutic applications in neurodegenerative diseases. Signal transduction and targeted therapy. 2024 Feb 16;9(1):37.*
25. *Jia X, Wang Q, Liu M, Ding JY. The interplay between gut microbiota and the brain-gut axis in Parkinson's disease treatment. Frontiers in Neurology. 2024 May 29;15:1415463.*
26. *Zhong L, Cai B, Wang Q, Li X, Xu W, Chen T. Exploring the neuroprotective mechanism of curcumin inhibition of intestinal inflammation against Parkinson's disease based on the gut-brain Axis. Pharmaceuticals. 2022 Dec 27;16(1):39.*
27. *Derkinderen P, Cossais F, Kulcsárová K, Škorvánek M, Sellier-Montaigne L, Coron E, Leclair-Visonneau L, Cerri S, Pellegrini C, Rolli-Derkinderen M. How leaky is the gut in Parkinson's disease?. EBioMedicine. 2025 Jul 1;117.*
28. *Menozzi E, Schapira AHV, Borghammer P. The Gut-Brain Axis in Parkinson disease: Emerging Concepts and Therapeutic Implications. Mov Disord Clin Pract. 2025 Jul;12(7):904-916. doi: 10.1002/mdc3.70029. Epub 2025 Mar 13. PMID: 40079755; PMCID: PMC12275011.*