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The Gut Brain Connection

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Abstract

The gut-brain connection is a bidirectional communication system that links the gut microbiome to the central nervous system (CNS). The gut-brain axis communicates through a variety of mechanisms, including the release of hormones, neurotransmitters, and cytokines. These signaling molecules can travel from the gut to the brain and vice versa, influencing various physiological and cognitive functions. Emerging therapeutic strategies targeting the gut-brain connection include probiotics, prebiotics, and faecal microbiota transplantation (FMT). Probiotics are live microorganisms that are similar to the beneficial bacteria that are naturally found in the gut. Prebiotics are non-digestible fibers that feed the beneficial bacteria in the gut. FMT is a procedure in which faecal matter from a healthy donor is transplanted into the gut of a person with a diseased microbiome. Probiotics, prebiotics, and FMT have been shown to be effective in treating a variety of gastrointestinal disorders, and there is growing evidence that they may also be effective in treating neurological and psychiatric disorders. This review explores the emerging field of the gut-brain connection, focusing on the communication pathways between the gut microbiome and the central nervous system. We summarize the potential roles of gut dysbiosis in various neurological and psychiatric disorders. Additionally, we discuss potential therapeutic strategies, research limitations, and future directions in this exciting area of research. More research is needed to fully understand the mechanisms underlying the gut-brain connection and to develop safe and effective therapies that target this pathway. However, the findings to date are promising, and there is the potential to revolutionize the way we diagnose and treat a variety of neurological and psychiatric disorders.

Keywords

Gut-Brain Connection, Gut-Brain Axis, Enteric Nervous System, Microbiota, Neurotransmitters, Neuroinflammation and Mental Health

1. Introduction & Background

The gut-brain connection, also known as the gut-brain axis, is a complex bidirectional communication system that links the gut microbiome to the central nervous system (CNS). This system plays a vital role in regulating various physiological and cognitive functions, including mood, cognition, and behavior. The gut microbiome is a diverse community of trillions of microorganisms that reside in the gastrointestinal tract [1]. These microorganisms play a crucial role in digestion, nutrient absorption, and immune functions [2]. Recent research has shown that the gut microbiome also plays a role in regulating the normal functioning of CNS [3].

The gut-brain axis communicates through a variety of mechanisms, including the release of hormones, neurotransmitters, and cytokines [4]. These signaling molecules can travel from the gut to the brain and vice versa, influencing various physiological and cognitive functions. For example, the gut microbiome produces short-chain fatty acids (SCFAs), which are small molecules that can cross the blood-brain barrier and interact with receptors in the brain [5]. SCFAs have been shown to have a variety of beneficial effects on the CNS, including reducing inflammation, improving mood, and enhancing cognitive function [6].

The gut-brain axis also communicates through the vagus nerve, a nerve that connects the gut to the brain. The vagus nerve transmits signals in both directions, allowing the gut and brain to communicate with each other [7].

The gut-brain connection is thought to play a role in a variety of neurological and psychiatric disorders, including depression, anxiety, autism, and Alzheimer's disease. Research has shown that people with these disorders often have alterations in their gut microbiome [8]. For example, people with depression have been shown to have lower levels of certain beneficial bacteria in their gut. These bacteria produce SCFAs, which have antidepressant effects [9]. The gut-brain connection is a rapidly developing field of research with the potential to revolutionize the way we diagnose and treat neurological and psychiatric disorders.

Rationale for this narrative review: This narrative review will provide a comprehensive overview of the current state of knowledge on the gut-brain connection, with a focus on its role in neurological and psychiatric disorders. The review will cover the following topics: The composition and function of the gut microbiome; The mechanisms of communication between the gut microbiome and the CNS; The role of the gut-brain connection in neurological and psychiatric disorders; Emerging therapeutic strategies targeting the gut-brain connection.

This review is timely and important because the gut-brain connection is a rapidly developing field of research with the potential to revolutionize the way we diagnose and treat neurological and psychiatric disorders. The review will provide a valuable resource for clinicians, researchers, and patients who are interested in learning more about the gut-brain connection and its implications for health and disease.

2. Methodology

A systematic approach was employed to conduct a comprehensive narrative review, focusing on the gut-brain connection and its implications for betterment of human health. A thorough search of electronic databases, including PubMed, Scopus, Google scholar and Web of Science was conducted to identify relevant scientific articles published between January 2000 and October 2023. The search strategy utilized a combination of keywords, including "gut-brain connection," "gut-brain axis," "enteric nervous system," "microbiota," "neurotransmitters," "neuroinflammation," and "mental health."

Inclusion criteria were defined to ensure the selection of articles most relevant to the topic of interest. Studies written in English, conducted in humans or animal models, and focusing on the interplay between the gut and the brain were considered for inclusion. The initial search yielded a total of 1200 articles, which were then screened based on their title and abstract. Duplicate articles were removed, resulting in a final pool of 400 articles for full-text assessment.

The full-text assessment involved a meticulous examination of each article's content to determine its relevance and quality. Articles that met the inclusion criteria were further analysed for their methodology, study design, and key findings. References within these articles were also reviewed to identify additional relevant studies that may have been missed during the initial search.

Data extraction was performed to collect pertinent information from the selected articles. This included details on the study population (e.g., humans, animals), research design (e.g., observational, experimental), sample size, intervention or exposure, and outcome measures. The extracted data were systematically organized into tables and charts to facilitate data synthesis and comparison across studies.

The findings from the selected studies were synthesized narratively to provide a comprehensive overview of the gut-brain connection. Key themes and patterns identified across the literature were discussed, and important knowledge gaps were highlighted. Clinical implications and potential therapeutic avenues were also explored based on the evidence presented.

It is important to note that this narrative review article is limited to the studies available in the selected databases and the inclusion criteria applied. The exclusion of studies published in languages other than English may introduce a potential language bias. Furthermore, the review does not include unpublished data or gray literature, which could have provided additional insights into the topic.

3. Review

3.1. Gut-Brain Connection

The following are some key findings from the narrative review on the gut-brain connection, with a focus on its role in neurological and psychiatric disorders:

The gut microbiome is essential for normal brain development and function. Studies have shown that animals with disrupted gut microbiomes exhibit a variety of behavioral and cognitive impairments, including anxiety, depression, and impaired learning and memory. Table 1 describes the Key mechanisms of the Gut-Brain connection. The gut microbiome communicates with the CNS through a variety of mechanisms, including the vagus nerve, SCFAs, and other signaling molecules.

The vagus nerve is a major nerve that connects the gut to the brain. It transmits signals in both directions, allowing the gut and brain to communicate with each other. SCFAs are small molecules that are produced by the gut microbiome

Table 1. Key mechanisms of the gut-brain connection.

Mechanism	Description	Role in the gut-brain connection	Potential implications for neurological and psychiatric disorders
Vagus nerve	A bidirectional nerve that connects the gut to the brain and can transmit signals in both directions.	The vagus nerve plays a key role in regulating gut-brain communication. It can transmit signals from the gut to the brain about the gut microbiome, food intake, and inflammation. The vagus nerve can also transmit signals from the brain to the gut to control gut motility and secretion.	Dysfunction of the vagus nerve has been implicated in a number of neurological and psychiatric disorders, including depression, anxiety, and autism [42].
Short-chain fatty acids (SCFAs)	Produced by the fermentation of fiber by gut bacteria, SCFAs can cross the blood-brain barrier and interact with receptors in the brain.	SCFAs have a number of effects on the brain, including reducing inflammation, improving cognitive function, and regulating mood.	Alterations in SCFA levels have been observed in a number of neurological and psychiatric disorders, including depression, anxiety, and Alzheimer's disease [8].
Cytokines	Signalling molecules that are produced by the immune system, cytokines produced in the gut can communicate with the brain through the vagus nerve and other pathways.	Cytokines play a role in regulating gut inflammation and immune function. They can also communicate with the brain to regulate mood and behavior.	Elevated levels of cytokines have been observed in a number of neurological and psychiatric disorders, including depression, anxiety, and schizophrenia [43].
Neurotransmitters	Chemical messengers that are used by neurons to communicate with each other, neurotransmitters produced in the gut can communicate with the brain through the vagus nerve and other pathways.	Neurotransmitters such as serotonin, dopamine, and GABA play a key role in regulating mood, cognition, and behavior.	Alterations in neurotransmitter levels have been observed in a number of neurological and psychiatric disorders, including depression, anxiety, and Parkinson's disease [44].

and can cross the blood-brain barrier to interact with receptors in the brain. SCFAs have been shown to have a variety of beneficial effects on the CNS, including reducing inflammation, improving mood, and enhancing cognitive function. The gut-brain connection is thought to play a role in a variety of neurological and psychiatric disorders, including depression, anxiety, autism, Multiple sclerosis and Alzheimer's disease. Research has shown that people with these disorders often have alterations in their gut microbiome. For example, people with depression have been shown to have lower levels of certain beneficial bacteria in their gut. These bacteria produce SCFAs, which have antidepressant effects [10].

Vagus nerve stimulation: Gut microbiome acts as the conductor, influencing gene expression through its chemical messengers, the vagus nerve serves as a vital conductor's baton in the gut-brain orchestra. Vagus nerve stimulation (VNS) is a promising therapeutic approach that involves sending electrical impulses directly to the nerve. This stimulation can mimic the natural activity of the vagus nerve, potentially influencing various aspects of gut health and brain function. Studies suggest that VNS may be beneficial for treating conditions like inflammatory bowel disease, irritable bowel syndrome, and even depression and anxiety. By directly influencing the vagus nerve, VNS can potentially modulate the gut-brain communication pathway, potentially restoring balance and alleviating symptoms. While research on VNS is still ongoing, its potential to act as a direct conductor in the gut-brain orchestra offers exciting possibilities for future treatments. It underscores the complex interplay between our gut microbes, our genes, and the intricate nervous system, highlighting the potential for targeted interventions to promote health and well-being [11].

As shown in **Table 2**, the emerging therapeutic strategies targeting the gut-brain connection include probiotics, prebiotics, and faecal microbiota transplantation [12]. Probiotics are live microorganisms that are similar to the beneficial bacteria that are naturally found in the gut. Prebiotics are non-digestible fibers that feed the beneficial bacteria in the gut. Faecal microbiota transplantation (FMT) is a procedure in which faecal matter from a healthy donor is transplanted into the gut of a person with a diseased microbiome. Probiotics, prebiotics, and FMT have been shown to be effective in treating a variety of gastrointestinal disorders, and there is growing evidence that they may also be effective in treating neurological and psychiatric disorders [13].

Research has shown that people with these following disorders often have alterations in their gut microbiome.

3.2. Depression

Depression is a common mental health disorder that is characterized by persistent feelings of sadness and loss of interest in normal activities. Research has shown that people with depression often have lower levels of certain beneficial bacteria in their gut. These bacteria produce SCFAs, which have antidepressant

Table 2. Emerging therapeutic strategies targeting the gut-brain connection.

Therapeutic strategy	Description	Mechanism of action	Potential benefits
Probiotics	Live microorganisms that are similar to the beneficial bacteria that are naturally found in the gut.	Probiotics can help to restore the balance of gut bacteria and improve gut health.	Probiotics have been shown to be effective in treating a variety of neurological and psychiatric disorders, including depression, anxiety, autism, and Alzheimer's disease [45].
Prebiotics	Non-digestible fibers that feed the beneficial bacteria in the gut.	Prebiotics help to promote the growth of beneficial bacteria in the gut.	Prebiotics have been shown to improve gut health and reduce inflammation. Prebiotics are also being investigated as a potential treatment for a variety of neurological and psychiatric disorders [46].
Fecal microbiota transplantation (FMT)	A procedure in which fecal matter from a healthy donor is transplanted into the gut of a person with a diseased microbiome.	FMT can help to restore the balance of gut bacteria and improve gut health.	FMT has been shown to be effective in treating recurrent Clostridium difficile infection. FMT is also being investigated as a potential treatment for a variety of other conditions, including neurological and psychiatric disorders [47].
Vagus Nerve Stimulation	Non-invasive or surgically implanted device that stimulates the vagus nerve, influencing brain activity and gut function.	Reduces inflammation, improve mood and emotional regulation, potentially modulate gut microbiota. Left cervical VNS is an approved therapy for refractory epilepsy and for treatment resistant depression.	May offer benefits for treatment-resistant depression, epilepsy, and chronic pain. The relationship between depression, inflammation, metabolic syndrome, and heart disease might be mediated by the vagus nerve [11].

effects. A study published in the Nature Communication found that mice with disrupted gut microbiomes were more likely to develop depressive-like behaviors. However, when the mice were given a probiotic supplement, their depressive-like behaviors were found to be reduced [14]. Another study published in the journal Translational Psychiatry found that people with depression had lower levels of certain beneficial bacteria in their gut than people without depression. The researchers also found that people with depression who took a probiotic supplement for few weeks showed significant improvements in their mood and depressive symptoms [15].

3.3. Anxiety

Anxiety is another common mental health disorder that is characterized by excessive worry and fear. Research has shown that people with anxiety often have alterations in their gut microbiome. A study published in the journal Molecular

Psychiatry found that mice with disrupted gut microbiomes were more likely to develop anxiety-like behaviors. However, when the mice were given a probiotic supplement, their anxiety-like behaviors were found to be reduced [16].

Another study published by Xiong *et al.* in 2023 found that people with anxiety had lower levels of certain beneficial bacteria in their gut than people without anxiety. The researchers also found that people with anxiety who took a probiotic supplement for eight weeks showed significant reductions in their anxiety symptoms [17].

3.4. Autism

Autism is a neurodevelopmental disorder that is characterized by deficits in social communication and interaction and restricted, repetitive patterns of behavior, interests, or activities. Research has shown that people with autism often have alterations in their gut microbiome. A study published in the journal Cell found that children with autism had lower levels of certain beneficial bacteria in their gut than children without autism. The researchers also found that children with autism who took a probiotic supplement showed significant improvements in their social communication and interaction skills [18]. Another study published by Sivamaruthi *et al.* found that people with autism had lower levels of certain beneficial bacteria in their gut than people without autism. The researchers also found that people with autism who took a probiotic supplement showed significant reductions in their repetitive behaviors and restricted interests [19]. It has been known that the consumption of probiotics confers several health benefits by positive amendment of gut microbiota. The influence of probiotic intervention in children with ASD has also been reported and it has been considered as an alternative and complementary therapeutic supplement for ASD.

3.5. Alzheimer's Disease

Alzheimer's disease is a neurodegenerative disorder that is characterized by progressive cognitive decline and memory loss. Research has shown that people with Alzheimer's disease often have alterations in their gut microbiome. A study published by Chandra *et al.* found that mice with disrupted gut microbiomes were more likely to develop amyloid plaque and tau tangles, which are the hallmarks of Alzheimer's disease. However, when the mice were given a probiotic supplement, the development of amyloid plaque and tau tangles was reduced [20]. As the body's master regulator of inflammation, the gut microbiome (GMB) plays a critical role in the onset and course of disorders affecting both peripheral and central inflammation [21]. Comprehending the ways in which the GMB can impact the advancement of Alzheimer's disease (AD) might unveil a significant therapeutic target capable of regulating several pathogenic pathways. Since early research showed that GMB change has a substantial impact on AD-related pathology and that GMB composition is considerably different in

AD patients compared to healthy controls [22].

3.6. Parkinson's Disease

PD is mainly characterized by both motor and non-motor disturbances. PD is primarily distinguished by abnormalities that are both motor and non-motor. The most common symptoms on the motor side are rigidity, resting tremor, and slowness of movement. Significant impairment is a result of non-motor factors such as autonomic dysfunction, mood deflection, depression, sensory alternations, sleep alternations, and cognitive problems. The build-up of α-synuclein in both the central and peripheral nerve systems is reflected in this broad clinical spectrum [23]. Most PD patients have symptoms related to their gastrointestinal tract (GI). Patients with Parkinson's disease (PD) have been shown to exhibit a range of gastrointestinal symptoms, including dysphagia, constipation, nausea, changed bowel habits, and defecatory dysfunction [24].

3.7. Multiple Sclerosis

Multiple sclerosis (MS) is a complex autoimmune disease that predominantly affects young adults, causing damage to the central nervous system, specifically the brain and spinal cord. Emerging research has revealed the involvement of gut microbiota in the pathophysiology of MS, offering a fresh viewpoint on the gut-brain axis. Immunosuppressive drugs and disease-modifying treatments (DMTs) used in MS treatment may have an effect on the gut microbiota. Alterations in the composition of the gut microbiota have been associated with a number of therapies, such as fingolimod, dimethyl fumarate, interferon-beta, and glatiramer acetate [25]. Alemtuzumab induces systemic lymphocyte depletion, which has an effect on the gut flora [26]. Steroids may change the composition of the gut flora and are commonly used to manage relapses [27]. Among other symptomatic drugs, antidepressants and cannabis may affect the composition of the gut flora [28].

These are just a few examples of the growing body of research on the gut-brain connection and its role in neurological and psychiatric disorders. More research is needed to fully understand the mechanisms underlying the gut-brain connection and to develop safe and effective therapies that target this pathway.

The research on the gut-brain connection is still in its early stages, but the findings to date are promising. More research is needed to fully understand the mechanisms underlying the gut-brain connection and to develop safe and effective therapies that target this pathway. One of the key challenges in researching the gut-brain connection is the complexity of the gut microbiome. The gut microbiome is a diverse community of trillions of microorganisms, and each individual has a unique microbiome fingerprint [29]. This makes it difficult to identify the specific bacteria that are involved in the gut-brain connection and their mechanisms of action.

Another challenge is the lack of standardized methods for measuring the gut-brain connection. There are a variety of different techniques that can be used to measure the gut microbiome and its activity, but these techniques are not always consistent. This makes it difficult to compare the results of different studies and to draw conclusions about the gut-brain connection [30].

Despite these challenges, the research on the gut-brain connection is rapidly advancing. New technologies are being developed to study the gut microbiome in more detail, and new methods are being developed to measure the gut-brain connection. Emerging technologies including engineered organoids derived from human stem cells, high-throughput culturing, and microfluidics assays allowing for the introduction of novel approaches will improve the efficiency and quality of microbiome research [31].

3.8. Research on the Gut Microbiome and Bioinformatics Tools

In order to improve our understanding of complex microbial communities, their internal relationships, and their interactions with hosts and environments, microbiome bioinformatics aims to provide computational methodologies and procedures that complement experimental approaches. With a focus on processing high throughput sequencing of variable regions of bacterial 16S ribosomal genes and an emphasis on exploratory data analysis and taxonomic composition visualisation, current bioinformatic practise is largely encapsulated in the software platforms Mothur [32] and QIIME [33]. Through complementing taxonomic diversity analysis, whole genome shotgun sequencing (WGS), and metatranscriptomic sequencing, emerging bioinformatics tools improve these methods with greater statistical rigour and offer insight into the complex environmental context [31].

3.9. Gut Microbiome and Next-Generation Sequencing (NGS)

Next-Generation Sequencing (NGS) technology has made it possible to conduct investigations on intricate microbial systems more successfully than in the past. However, data might be skewed, over- or underestimating bacterial abundance due to biases imposed by PCR-based sequencing technologies [34]. Primer efficiency, PCR amplification settings, sequencing platform, bioinformatics pipeline, and procedures for DNA extraction and sample handling can all induce biases into the results of 16S rRNA amplicon sequencing [35]. These internal biases are a major contributing factor to the difficulty in reproducing results in microbiome investigations, as demonstrated by the Microbiome Quality Control project (MBQC), a consortium of scientists working to standardise microbiome studies [36].

One of the most promising areas of research on the gut-brain connection is the development of new probiotic strains and formulations that are specifically targeted to treat neurological and psychiatric disorders [37]. One recent meta-analysis of probiotic intervention in clinical depression found that probiotics are best used as an adjunct to antidepressants rather than as a stand-alone treatment, despite the fact that the majority of pre-clinical studies and some clinical studies have demonstrated the efficacy of probiotics as a stand-alone treatment in depressive disorders [38]. Probiotics could be used as a supplement to antidepressants to address certain depressive symptoms.

3.10. Mechanism of Epigenetics

A different angle on the theoretical understanding of the dynamic interaction between the gut microbiota and the host's genome within the microbiota-gut-brain axis (MGBA) is revealed by epigenetic mechanisms, which integrate environmental signals to modify gene expression, independent of changes in the actual DNA sequence. The host's gene expression can change heritably through well-studied epigenetic mechanisms such as histone tail modifications, DNA methylation, and non-coding RNAs. Enzyme-mediated changes to DNA and histones can either enhance or decrease the expression of a gene [39]. One possible mechanism by which the gut microbiota modulates these epigenetic changes is through its metabolites (SCFAs; butyrate, acetate, and propionate), which can do so by directly inhibiting enzymes or by changing the availability of substrates necessary for enzymatic activity [40].

This complex interplay between the gut microbiome and epigenetic machinery highlights the fascinating potential for microbial communities to shape not only our individual health but also the health of future generations. Trillions of commensal microbes, known as the microbiota, are constantly present in the gastrointestinal system and operate as environmental triggers that might influence a host's health or illness. Microbial signals are incorporated not only through documented bacterial sensing mechanisms but also through epigenetic alterations that adjust the transcriptional programme of host cells without changing the underlying genetic code. Epigenetic modifications that are sensitive to the microbiota encompass adjustments made to DNA or histones, in addition to the control of non-coding RNAs. Although epigenetic pathways responsive to microbiota have been identified in peripheral tissues and local intestine cells, more investigation is needed to completely understand the intricate interplay between the microbiota and the host [41].

4. Future Research Points on the Gut-Brain Connection

The gut-brain connection is a rapidly developing field of research with the potential to revolutionize the way we diagnose and treat a variety of neurological and psychiatric disorders. However, there are still many unanswered questions about the mechanisms underlying the gut-brain connection and the development of safe and effective therapies that target this pathway.

Some specific areas of future research on the gut-brain connection include:

1) Identifying the specific gut bacteria that are involved in the gut-brain connection and their mechanisms of action. This could be done using a variety of

techniques, including metagenomics, metabolomics, animal models, and human intervention studies.

2) Developing new probiotic strains and formulations that are specifically targeted to treat neurological and psychiatric disorders. This could be done by screening large libraries of probiotic strains for their ability to produce specific signaling molecules, to interact with specific receptors in the brain, or to modulate specific gut-brain signaling pathways.

3) Investigating the use of prebiotics, postbiotics, and faecal microbiota transplantation (FMT) in the treatment of neurological and psychiatric disorders. It can be achieved by conducting clinical trials to assess the safety and efficacy of these therapies, as well as by exploring the optimal dose, duration of treatment, and patient selection criteria.

4) Developing new and innovative ways to study the gut-brain connection using big data analytics, machine learning, and other emerging technologies to identify new patterns and associations between the gut microbiome and neurological and psychiatric disorders.

5) Investigating the role of the gut-brain connection in the development and progression of neurological and psychiatric disorders by conducting longitudinal studies to track the changes in the gut microbiome over time and by correlating these changes with the onset and progression of neurological and psychiatric symptoms.

6) Exploring the potential of gut-brain-targeted therapies for the prevention of neurological and psychiatric disorders by identifying high-risk individuals and conducting intervention studies to assess the efficacy of gut-brain-targeted therapies in preventing the onset of neurological and psychiatric disorders.

In addition to these specific areas of research, it is also important to continue to investigate the role of the gut-brain connection in a wide range of neurological and psychiatric disorders, as well as in other medical conditions, such as cardiovascular disease, metabolic disorders, and cancer.

By continuing to invest in research on the gut-brain connection, we can make significant progress in improving the diagnosis, prevention, and treatment of a wide range of human diseases.

Study Limitations

This narrative review has several limitations. First, it is limited by the quality and quantity of the available literature. The field of gut-brain research is rapidly developing, and new findings are emerging at a rapid pace. As a result, it is possible that some relevant studies were not included in this review.

5. Conclusions

The gut-brain connection is a bidirectional communication system that links the gut microbiome to the central nervous system (CNS). This system plays a vital role in regulating various physiological and cognitive functions, including mood, cognition, and behavior.

The gut microbiome is a diverse community of trillions of microorganisms that reside in the gastrointestinal tract. These microorganisms produce a variety of signalling molecules, including hormones, neurotransmitters, and cytokines, which can communicate with the CNS through a variety of mechanisms.

The gut-brain connection is thought to play a role in a variety of neurological and psychiatric disorders, including depression, anxiety, autism, MS and Alzheimer's disease. Research has shown that people with these disorders often have alterations in their gut microbiome.

Emerging therapeutic strategies targeting the gut-brain connection include probiotics, prebiotics, and faecal microbiota transplantation (FMT). Probiotics are similar to the beneficial bacteria that are naturally found in the gut. Prebiotics are non-digestible fibers that feed the beneficial bacteria in the gut. FMT is a procedure in which fecal matter from a healthy donor is transplanted into the gut of a person with a diseased microbiome.

The research on the gut-brain connection is still in its early stages, but the findings to date are promising. More research is needed to fully understand the mechanisms underlying the gut-brain connection and to develop safe and effective therapies that target this pathway. However, the gut-brain connection is a promising new avenue for the diagnosis, prevention, and treatment of a variety of neurological and psychiatric disorders.

Second, this review is limited by its focus on neurological and psychiatric disorders. The gut-brain connection is thought to play a role in a wide range of other medical conditions, such as cardiovascular disease, metabolic disorders, and cancer. However, these conditions were outside the scope of this review.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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