

**DIETARY FACTORS, GUT MICROBIOME DYSBIOSIS, AND
NEUROINFLAMMATION: A REVIEW OF CURRENT RESEARCH*****Santhoshkumar R.**

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ABSTRACT

The review provides a comprehensive summary of the current research on the impact of dietary factors and gut microbiome dysbiosis on neuroinflammation. The gut microbiome plays a crucial role in maintaining overall health, and alterations in its composition and diversity have been linked to several health conditions, including neuroinflammation. The review delves into the underlying mechanisms involved in the gut-brain axis and emphasizes potential therapeutic approaches that aim to address this complex relationship. The impact of dietary factors on the gut microbiome and its relationship with neuroinflammation is discussed with a focus on high-fiber diets, high-protein diets, high-sugar diets, and Western diets. Manipulating the gut microbiome through interventions such as probiotics, prebiotics, and other dietary factors holds promise as a potential therapeutic approach for various diseases. The review highlights the significance of the gut microbiome in various aspects of human health, including neuroinflammation, and emphasizes the need for further investigation into this complex relationship.

KEYWORDS: Gut Microbiota, Diet, Neuroinflammation.**INTRODUCTION**

The human gastrointestinal tract is home to a vast and diverse community of microorganisms, collectively known as the gut microbiome. These bacteria, along with the genes they harbor, play a crucial role in the overall well-being of an individual. Extensive research has shed light on the significance of the gut microbiota in various aspects of human health, ranging from metabolism and nutrition to physiology and immune function. The gut microbiome is a complex ecosystem consisting of trillions of bacterial cells residing in the digestive tract.^[1] Moreover, emerging research suggests that alterations in the composition and diversity of the gut microbiota, known as dysbiosis, are associated with several health conditions. Imbalances in the gut microbiome have been linked to gastrointestinal disorders, such as inflammatory bowel disease (IBD), irritable bowel syndrome (IBS), and colorectal cancer.^[2] Manipulating the gut microbiome through interventions such as probiotics, prebiotics, and other dietary factors holds promise as a potential therapeutic approach for various diseases.^[3]

Neuroinflammation, a chronic inflammatory response in the brain, has emerged as a significant pathological alteration seen in the early stages of numerous neurodegenerative disorders.^[4]

The gut microbiota has gained recognition as a significant factor affecting central nervous system balance and function.^[5] In recent times, an increasing body of evidence indicates that changes in dietary habits and the composition of the gut microbiome have a substantial impact on the regulation of neuroinflammation.^[6] The dynamic interaction between the gut microbiota and the brain, referred to as the gut-brain axis, has attracted significant interest as a promising avenue for comprehending the underlying mechanisms involved in neuroinflammation.^[7] The purpose of this review is to offer a thorough and inclusive summary of the present knowledge regarding the impact of dietary factors and imbalances in the gut microbiome on neuroinflammation. It delves into the underlying mechanisms and emphasizes potential

therapeutic approaches that aim to address this complex relationship.

Overview of the gut microbiome and its composition

The human gut microbiome comprises a vast array of microorganisms, including bacteria, viruses, fungi, and protozoa and coexist in a commensal relationship within the human intestinal tract.^[8] It is intriguing to observe that while the functions of the gut microbiota remain largely consistent among individuals, each person possesses a distinct combination of bacterial species within their gut microbiota. This variation arises from both inter-individual and intra-individual differences that occur throughout a person's lifespan.^[9] The microbiome plays a significant part in sustaining overall health. One of its key functions is to provide protection against harmful pathogens and a notable example is the production of short-chain fatty acids (SCFAs) by the microbiota through the fermentation of complex carbohydrates which serve as an important energy source for the body.^[10] The microbiome provides host protection against pathogenic bacteria through colonization resistance, nutrient competition, and maintenance of optimal intestinal pH. It directly prevents attachment of pathogens, outcompetes them for nutrients, and ensures a suitable pH in the intestines.^[11] It also synthesizes several vitamins and amino acids, and synchronizes fat metabolism.^[12]

Conversely, the microbiome also plays a significant role in immune system control system's development. A healthy microbiome exhibits an anti-inflammatory function by suppressing the activity of histone deacetylases within regulatory T cells through the activation of G-protein coupled receptors. This interaction helps maintain a balanced immune response and contributes to overall immune system health.^[10]

Factors influencing gut microbiome diversity and balance

High-fibre diets

Digestible carbohydrates undergo breakdown in the small intestine and are promptly released as glucose into the bloodstream. In contrast, non-digestible carbohydrates, also referred to as dietary fiber, reach the large intestine. Among them, fermentable fibers, known as microbiota-accessible carbohydrates (MACs), are easily fermented by bacteria in the colon, leading to the production of short-chain fatty acids. This process has important implications for gut health and overall well-being. Fiber has a role in nourishing the gut microbiota, which, in turn, offers protection against diet-induced obesity by restoring colon health through IL-22 mediation.^[13] A fiber-deficient diet can disrupt the body's balance of health, leading to the initiation of disease pathways. Enhancing the gut microbiota profile through personalized nutrition and targeted supplementation is a proactive approach to minimize the effects of immunosenescence in older individuals and to boost immune response in immunocompromised patients.^[14,15]

Moreover, high-fat or high-sugar diet exhibit a greater susceptibility to disruptions in circadian rhythm within their gut microbiome.^[16]

High-protein diet

The effect of protein foods on gut microbiota depends on several factors: amino acid sequence, the amino acid type, the polypeptide structure and charge of the protein.^[17] The condition of proteins, influenced by factors such as food processing, preparation, gastric digestion, and collaboration with other food components, can alter the composition of the gut microbiota. This, in turn, affects the production of various peptides during digestion, creating a reciprocal impact on the gut microbiota. Understanding the complex interplay between protein modifications and gut microbiota is crucial in comprehending the dynamic relationship between diet and microbial communities in the gut. In addition, gut microbiota has the ability to metabolize amino acids into various microbial metabolites, including short-chain fatty acids (SCFAs), polyamines, hydrogen sulfide, phenols, and indoles which has important roles in various physiological functions that impact both host health and disease.^[18]

Yin J et al, conducted a study on pig and found that, pigs that underwent dietary lysine restriction (30%) exhibited notable changes in the plethora of specific bacterial species. There was an observed increase in the abundances of *Escherichia-Shigella*, *Aquabacterium*, and *Candidatus Methylophilum*. Conversely, a decrease in the abundances of *Bacteroides*, *Bacillus*, *Pasteurella*, *Clostridium sensu stricto*, *Faecalibacterium*, *Paucisalibacillus*, and *Lachnospirillum* was noted. These alterations in bacterial populations were attributed to the restricted metabolism of amino acids caused by the lysine restriction in their diet.^[19] Additionally the quantity of unprocessed protein that reaches the colon is influenced by the amount and how well proteins from various food sources are digested. This, in turn, can impact the makeup of the gut microbiota responsible for protein fermentation.^[20]

Consuming a diet rich in animal protein over an extended period has been linked to higher levels of *Alistipes*, *Bifidobacterium*, and *Bacteroides* in the gut microbiota, (against inflammation) while the presence of *Roseburia*, *Eubacterium rectale*, and *Ruminococcus bromii* tends to decrease. Conversely, when the primary source of protein comes from plants, higher abundances of *Lactobacilli* and *Bifidobacteria* are observed, along with an increase in the production of short-chain fatty acids.^[21,22]

High sugar diet

The high intake of dietary sugars is deeply linked to westernized diets, which include heavily processed foods and beverages with sugar additives and are significantly linked to an elevated chance of developing health problems.^[23,24] In fact, the creation of dental caries,

hyperactivity, obesity, diabetes, cardiovascular disease, hypertension, fatty liver disease, dyslipidemias, and even some cancers have all shown to be significantly influenced by the high consumption of sweetened foods. And the same disease conditions depict a dysbiotic gut condition also.^[25] Excessive consumption of sugar appears to disrupt the equilibrium of the microbiota, leading to alterations in the relative abundance of Proteobacteria and Bacteroidetes. This imbalance is connected to a rise in pro-inflammatory characteristics, a decrease in immune-regulatory functions, and a reduced ability to maintain epithelial integrity.

Do et al. looked into the impact of a high-glucose or -fructose diet on the gut microbiota and also intestinal permeability, the levels of blood endotoxins, inflammation, and fat gain in a mouse model. It was discovered that high dietary sugar caused changes in the microbiota's composition, especially a decline in bacterial diversity and an increase in Proteobacteria. The mice developed metabolic endotoxemia and hepatic steatosis despite maintaining their normal weight, while the gut epithelium simultaneously displayed inflammatory alterations and decreased integrity^[26] have characteristics in common with microbial dysbiosis linked to metabolic disorders, inflammatory bowel diseases (IBD), and other human ailments.^[27]

Proteobacteria and other commensals, which specialise in digesting complex carbs typically have slower growth rates, may benefit from excess monosaccharides can harm other commensals since they lack absorption in the small intestine. Thus, in addition to supplying too much energy, a high sugar diet can also affect the microbiota, which can have negative effects.^[28] Additionally, Sun and colleagues demonstrated that feeding male Wistar rats a high-sucrose diet for 4 weeks dramatically raised their serum levels of triglycerides and cholesterol.^[29]

Western diet

A low intake of fruits, vegetables, and dietary fibre coupled with a high intake of sweets and saturated fats can be used to describe the so-called Western diet.^[30] The consumption of a Western dietary pattern has been correlated with an elevated susceptibility to metabolic disorders, obesity, and cardiovascular diseases. Furthermore, chronic systemic inflammation is recognized as a significant factor contributing to the development and progression of these conditions.^[31] Rastelli et al, conducted a study on mice in relation to western diet with high sugar and fat content, and came to the conclusion that the consumption of a high-fat diet alone has been found to potentially enhance gut permeability by altering the concentrations of bile acids and triggering barrier dysfunction mediated by deoxycholic acid. Moreover, the negative impact can be intensified by the influence of dietary fat on the composition and functionality of the microbiota.^[32]

Specifically, the high amounts of readily accessible acellular nutrients in a Western diet can facilitate increased growth potential as well as altered composition and metabolism of the gut microbiota. This can lead to a loss of microbial diversity and a bloom in bacteria capable of metabolizing simple sugars, which are normally not present in the distal colon. These changes in the gut microbiota can encourage many types of inflammatory disease because the environment in the gut provided by ultra-processed foods serves as a distinctive evolutionary breeding ground for microorganisms that can inflammation-related disease.^[33] For instance, both human and animal studies have demonstrated that pathogens, pathobionts, and other members of the microbiome can respond to a change in their environment (e.g., the presence of some emulsifiers) by increasing their expression of virulence factors, thereby increasing the pro-inflammatory potential of the microbiome. Additionally, increased quantities of endotoxin-producing bacteria in the digestive tracts of humans and animals can result in metabolic endotoxemia from a Western diet. These changes in the gut microbiota can lead to inflammation-related diseases, such as metabolic syndrome, type 2 diabetes, and cardiovascular disease.^[34]

Gut Microbiome Dysbiosis and Neuroinflammation

The gut microbiota, residing in our digestive system, exhibits variations in composition and function over the course of a day. These fluctuations are closely linked to our eating behaviors, such as how often we eat and the duration of our overnight fast.^[35,36] The intricate connection that facilitates communication between the gastrointestinal tract and the central nervous system is commonly referred to as the gut-brain axis. This axis plays a vital role in neuroinflammation, characterized by brain inflammation and its association with a range of neurological disorders.^[37] Imbalances in the gut microbiome, known as dysbiosis, can result in disrupted immune regulation and the development of chronic inflammation, ultimately impacting the well-being of the brain.^[38] Dysbiosis can lead to an increase in the production and release of lipopolysaccharides (LPS) from the outer membrane of certain bacteria. LPS is a potent pro-inflammatory molecule that can enter the bloodstream and trigger immune responses, including the activation of microglia and astrocytes in the brain.^[39] Other pro-inflammatory molecules includes short-chain fatty acids (SCFAs), neurotransmitters, and immune-modulating molecules.^[40] Short-chain fatty acids (SCFAs) have the capacity to directly impact the brain through various means, such as crossing the blood-brain barrier or interacting with immune cells and neurons.^[41] Additionally, the gut microbiota generates metabolites and neurotransmitters that possess the ability to directly influence brain function and inflammatory processes.^[42]

Microglia and astrocytes are crucial in neuroinflammation, playing essential roles in the development and progression of inflammatory processes

in the brain. Microglia, as immunocompetent cells, exhibit remarkable plasticity and express diverse innate immune receptors on their cell membranes. Activation of these receptors triggers signaling cascades leading to the production of inflammatory mediators. Repeated activation results in the release of proinflammatory substances, contributing to neuroinflammation and potential harm to surrounding brain cells. Astrocytes, on the other hand, act as mediators, propagating and amplifying inflammatory signals. They release various inflammatory molecules, cytokines, and chemokines, modulating the inflammatory environment in the brain. Both microglia and astrocytes can have both beneficial and detrimental effects, depending on the context. Understanding their interplay is crucial for developing targeted therapeutic approaches to effectively manage neuroinflammatory conditions.^[43] Further research is needed to unravel the complex mechanisms involved and identify targeted interventions to harness the potential of the gut-brain axis in managing neuroinflammatory disorders.

Modulation of the microbiota-gut-brain axis by antibiotics and probiotics plays a significant role in maintaining a healthy balance. When there is gut dysbiosis, characterized by an imbalance in the gut microbiota, it can lead to immune activation, dysbiosis can disrupt signaling through the vagus nerve, impacting communication between the gut and the brain. Additionally, a compromised gastrointestinal barrier can result in bacterial migration and inflammation, while pro-inflammatory cytokines can disrupt the permeability of the blood-brain barrier. Antibiotics can impede the growth of specific bacteria, and probiotics have the potential to restore a balanced gut microbiota in the microbiota-gut-brain process. By addressing dysbiosis and restoring a healthy gut microbiota, probiotics may help normalize communication within the microbiota-gut-brain axis, while antibiotics can selectively target harmful bacteria.^[44,45]

The composition and functionality of the gut microbiota are significantly influenced by dietary factors. Unhealthy dietary patterns, have been linked to dysbiosis and increased inflammation, while diets rich promote a beneficial gut microbiota and reduce neuroinflammatory processes. Restoring a healthy gut microbiota through dietary modifications and interventions like prebiotics, probiotics, and postbiotics may hold promise for alleviating neuroinflammation.^[46]

Management

Probiotics

Probiotics are live microorganisms that can confer health benefits to the host by modulating the gut microbiota. Recent studies have suggested that probiotics may also have immunomodulatory and anti-inflammatory effects on the central nervous system, which could be beneficial for treating neuroinflammation, a pathological process involved in various neurological disorders.^[47] Probiotics

may help to reduce neuroinflammation through several mechanisms. Probiotics can improve gut barrier function, alter microbiota composition, and reduce systemic inflammation, all of which may lead to a reduction in neuroinflammation. In addition, some strains of probiotics, such as *Bifidobacterium bifidum* BGN4, have anti-inflammatory properties and may be beneficial for individuals with eczema or irritable bowel syndrome. Probiotics have also been shown to increase the abundance of particular gut bacteria subpopulations, such as *Eubacterium* and *Clostridiales*, which are associated with higher levels of brain-derived neurotrophic factor (BDNF). BDNF is a protein known to protect against neuroinflammation, and higher levels of BDNF may contribute to the neuroprotective effects of probiotics. However, more research is needed to fully understand the mechanisms by which probiotics reduce neuroinflammation and to determine the most effective strains and dosages for specific health outcomes.^[48]

Kim et al. investigated the effects of probiotics on cognitive function and neuroinflammation in healthy older adults. Participants in the probiotic group received a supplement containing *Bifidobacterium bifidum* BGN4, while the placebo group received a placebo supplement. After 12 weeks, the probiotic group had an increase in mental flexibility (attention and executive function) compared to baseline and compared to the placebo group, as measured by the Korean version of the Consortium to Establish a Registry for Alzheimer's Disease test. In addition, the probiotic group had higher blood serum levels of BDNF and BDNF levels correlated with increased abundance of particular gut bacteria subpopulations (*Eubacterium* and *Clostridiales*), which indicates that the neuroprotective effects may have originated in the gut.^[49]

Prebiotics and fibre rich diet

Prebiotics are a type of dietary fiber that can selectively promote the growth or activity of beneficial bacteria in the gut, such as bifidobacteria and lactobacilli, and thus improve host health. Prebiotics are resistant to digestion and absorption in the small intestine, but can be fermented by the gut microbiota in the large intestine, producing short-chain fatty acids (SCFAs) and other metabolites that have various physiological effects.^[50] Prebiotics may reduce inflammation through the production of short-chain fatty acids (SCFAs) by gut microbes during the fermentation of prebiotic fibers. SCFAs such as butyrate have been shown to have anti-inflammatory effects and may help to regulate the immune system. Additionally, prebiotics may help to promote the growth of beneficial gut bacteria, which can help to prevent the overgrowth of harmful bacteria that can contribute to inflammation. Prebiotics that can be consumed to modulate the gut microbiota include fructooligosaccharides, galactooligosaccharides, inulin, and resistant starch.^[51]

Fiber-rich foods may help to reduce neuroinflammation by promoting the growth of beneficial gut bacteria and improving gut barrier function. Fiber is a type of carbohydrate that is not digested by the human body, but instead is fermented by gut bacteria in the large intestine. This fermentation process produces SCFAs such as butyrate, which have been shown to have anti-inflammatory effects and may help to regulate the immune system.^[52]

Nutritional supplements

Curcumin: Curcumin, a natural polyphenol found in the rhizome of the turmeric plant, is a remarkably versatile compound with a multitude of biological targets and a broad spectrum of beneficial effects. It possesses notable properties such as anti-inflammatory, anti-tumor, anti-oxidative, anti-amyloidogenic, metal-chelating, and cardiovascular protective effects.^[53] Numerous studies have documented the neuroprotective properties of curcumin in cellular and animal models of neurological disorders.^[54] Furthermore, curcumin can cross the blood-brain barrier and modulate the inflammatory response in the central nervous system.

Sorrenti et al., investigated the potential benefits of curcumin in preventing acute neuroinflammation and long-term memory impairment induced by systemic lipopolysaccharide (LPS) in mice. The results showed that the mice treated with curcumin before LPS injection had reduced neuroinflammation and microglia activation compared to the mice in the LPS group. Furthermore, the curcumin-treated mice showed improved long-term memory retention compared to the LPS group. The authors concluded that short-term treatment with curcumin can prevent acute neuroinflammation and long-term memory impairment induced by systemic LPS in mice.^[55]

Omega-3 Fatty Acids: Cerebral functions are influenced by specific nutrients, including omega-3 polyunsaturated fatty acids (PUFAs), which are integral components of the plasma membrane and play significant roles in various processes. These processes include promoting synaptic development and functionality, preserving synaptic integrity and plasticity, and contributing to neuroplasticity, ultimately leading to improved cognitive activity. The presence of omega-3 PUFAs is vital for optimal brain function and cognitive enhancement.^[56] The mechanism by which omega 3 fatty acid is through the production of specialized pro-resolving lipid mediators (SPMs), which are derived from omega-3 fatty acids and have potent anti-inflammatory and pro-resolving effects. SPMs can regulate the immune response and promote the resolution of inflammation, which is important in preventing chronic inflammation and tissue damage. Another proposed mechanism is through the modulation of gene expression and signaling pathways involved in inflammation. Omega-3 fatty acids can affect the expression of genes involved in inflammation, such as cytokines and chemokines, and

can also modulate signaling pathways involved in inflammation, such as the NF- κ B pathway. By doing so, omega-3 fatty acids can reduce the production of pro-inflammatory mediators and promote the production of anti-inflammatory mediators.^[57]

Omega-3 fatty acids can also affect the composition and function of cell membranes, which can influence the production of inflammatory mediators. Omega-3 fatty acids can increase the fluidity of cell membranes and alter the lipid rafts, which are specialized regions of the membrane involved in signaling and protein trafficking. By doing so, omega-3 fatty acids can affect the activity of membrane-bound enzymes and receptors involved in inflammation. Overall, the anti-inflammatory effects of omega-3 fatty acids are likely due to a combination of these mechanisms, which can regulate the immune response and promote the resolution of inflammation.^[58]

Vitamin D: Vitamin D has gained significant attention in various areas of biomedical research beyond its traditional role in skeletal and calcium metabolism. Its impact has been extensively studied in conditions such as cardiovascular diseases, neuroinflammation, and neurodegenerative diseases. This is attributed to the widespread presence of vitamin D receptors and the necessary enzyme (α 1-hydroxylase) for its activation, not only in internal organs and immune cells but also in key regions of the brain.^[59]

Vitamin D has been shown to modulate the innate and adaptive immune system, which is an important function in neuroinflammation. Literally, all cells of the immune system express the vitamin D receptor as a prerequisite for being amenable to vitamin D signaling. Vitamin D has a significant role in immune regulation during inflammation, particularly in multiple sclerosis (MS). It promotes the development of regulatory T cells and tolerogenic dendritic cells while inhibiting pro-inflammatory cell types like Th1 and Th17. Moreover, it interferes with antibody production and reduces pro-inflammatory cytokine secretion from cytotoxic CD8+ T cells, contributing to its immunomodulatory effects in neuroinflammatory conditions.^[60]

CONCLUSION

In conclusion, dietary factors and the gut microbiota plays a crucial role in maintaining neurological conditions, with dysbiosis being linked to several brain health conditions. Emerging research suggests that changes in dietary habits and the composition of the gut microbiome have a significant impact on the regulation of neuroinflammation. The gut-brain axis offers a promising avenue for comprehending the underlying mechanisms involved in neuroinflammation. Moreover, the gut microbiome can be manipulated through interventions such as probiotics, prebiotics, nutritional supplements and anti neuroinflammatory diet plans, which hold promise as potential therapeutic approaches for various neuroinflammatory conditions. Further

research is needed to fully understand the complex relationship between dietary factors, gut microbiome dysbiosis, and neuroinflammation, which may provide new therapeutic targets.

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