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Gut Microbiota and Nutritional Regulation of Metabolic Health and Neuroinflammation

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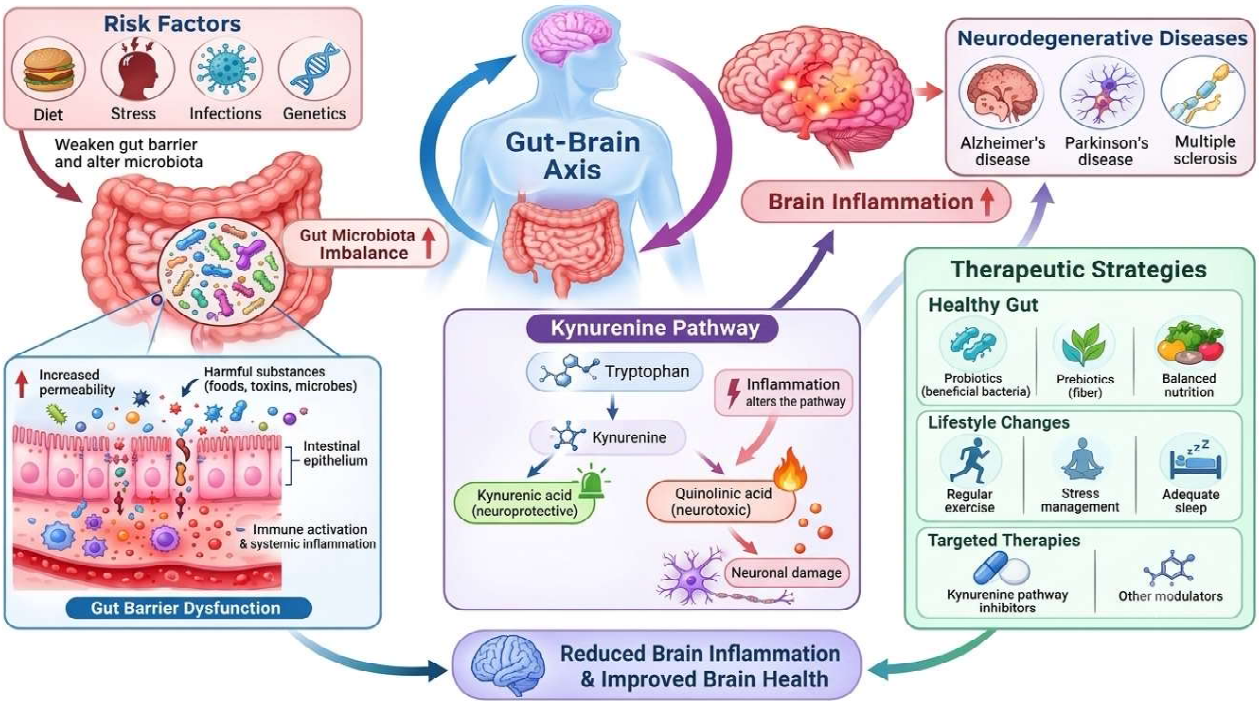
ABSTRACT

The number of people getting diseases like Alzheimer's Parkinson's and multiple sclerosis is going up. This is a problem all over the world. Even though scientists have studied these conditions a lot the exact reasons why they happen are still not clear. Most treatments today only help with the symptoms, not the causes. New studies show that the way the gut works and something called the kynurenine pathway might be important in these diseases. This means they could be targets for ways to treat and stop the diseases from getting worse. The gut is like a filter. It allows important nutrients to pass into the blood. It stops bad things from getting in. Things like food, stress, infections and genes can make the gut weaker. This makes it easier for stuff to get into the blood. This can cause inflammation that affects the brain through the gut-brain connection. The gut-brain axis is a system that connects the gut and the nervous system. When the balance of bad bacteria in the gut is off it can make the gut more permeable. This can lead to inflammation in the body and worse brain inflammation. The kynurenine pathway is the way the body breaks down a substance called tryptophan. This pathway is very important in the process. When there is inflammation the pathway can go wrong. This leads to chemicals like quinolinic acid, which can damage brain cells and make diseases worse. This review talks about what's known about these processes.

Keyword: *Gut microbiota; microbiome; gut-brain-axis; short chain fatty acids; kynurenine*



Graphical Abstract

INTRODUCTION

The gut microbiome has become a part of human health. It affects more than the way we digest food. It also plays a role in metabolism the balance of the system and the performance of the brain. Inside the intestines there is a variety of tiny living things. These include bacteria, archaea, fungi and viruses. These tiny organisms are always working with the food we eat and the tissues of our body. They help break down nutrients that the body can't handle on its own. They also make substances. What we eat changes the types of microbes that're in our body. It changes how they act. Eating foods in fiber like whole grains, fruits, vegetables and other plant-based foods gives energy to the good microbes. This leads to a process called fermentation. These kinds of foods can reduce the variety. Make the microbes less effective. This change can harm the gut lining. It can let parts of the microbes get into the blood. When the body cells meet these things, they can cause a listing small amount of inflammation. This kind of inflammation is now seen as a link between gut imbalance and problems, like obesity, diabetes and even brain disease (Thomas et al., 2022).

When the gut microbiota produces short chain fatty acids (SCFAs) or when bile acid metabolism changes, hormone release from the gut immune system function and overall metabolic processes can be affected (Nogal et al., 2021). When intestinal permeability is higher bacterial parts such as lipopolysaccharide can leak into the blood causing a low grade metabolic inflammation. Worsen metabolic problems eventually causing diabetes. Importantly the effects of gut imbalance go beyond just the body's metabolism. Increasing evidence shows that a two way communication system, called the

gut–brain axis works between the brain and the gut (Schneider et al., 2024; Agirman et al., 2021). Higher cytokine levels such as IL 1â, IL 6 and TNF á that come from dysbiosis can set off pathways that connect the brain and the immune system leading to neuro inflammation. Changes in metabolites together, with weakened blood brain barriers can also alter the activity of microglial cells and increase inflammation in the central nervous system. This might explain how problems outside the brain can affect brain health. Changes in brain activity and stress responses can impact the movement of the gut the strength of the gut barrier and the balance of gut microbes. This two-way connection shows that metabolic health and brain health are connected. There is evidence connecting diet, balance of gut bacteria metabolism problems and neuroinflammation (Schneider et al., 2024; Trisal et al., 2025). The exact reasons and how everything works together are not fully known. More research is needed to understand the roles of metabolites, gut permeability, short-chain fatty acids (SCFAs) bile-acid signaling, immune cell activity and inflammatory signals like IL-1â and IL-6. This study looks at the role of diet and gut microbiota in keeping us healthy. It also looks at how changes in what we eat and our gut bacteria can cause inflammation, metabolic conditions, like diabetes and brain inflammation.

GUT MICROBIOTA AS A NUTRITIONAL SENSOR

These metabolites can then interact with epithelial cells, immune cells and metabolic tissues. Because of this the makeup and function of the microbiota create a connection between what we eat and the body's overall physiology (Zhang et al., 2024). Nutritional components that are not well. Absorbed in the upper digestive system especially dietary fiber and resistant starch travel to the colon. There bacteria metabolize them. A major outcome of this process is the production of short-chain fatty acids or SCFAs. The main SCFAs are acetate, propionate and butyrate (Nogal et al., 2021; O'Riordan et al., 2022). These short-chain fatty acids (SCFAs) can pass through the barrier and enter the portal circulation. The role of the microbiota in sensing nutrition is very connected to the hosts receptors that sense metabolites. SCFAs can turn on G-protein-coupled receptors (GPCRs) like GPR41, GPR43 and GPR109A which're present in intestinal cells and immune cells. Microbial metabolites can change how cells send signals how immune cells work and how the body handles metabolism through these receptors. GPR43 for example is present types of immune cells and intestinal cells and it has been connected to keeping the intestines balanced and controlling inflammation. GPR109A can respond to butyrate and nicotinic acid. Short-chain fatty acids or SCFAs can influence how regulatory T-cells, also known as Treg cells grow and stay balanced. This helps control how the immune system reacts to what's happening inside the body (Fig. 1). These effects happen through GPCR signaling and by blocking histone deacetylases. This shows that microbial metabolites can change how cell work by using signaling pathways and affecting gene activity (O'Riordan et al., 2022; De Vos et al., 2022).

NUTRIENTS, DIETARY PATTERNS, AND MICROBIAL ECOLOGY

Genetics, the environment, and general health matter a lot but diet can still change the community of microbes in the gut. The way people eat affects the change they see in their

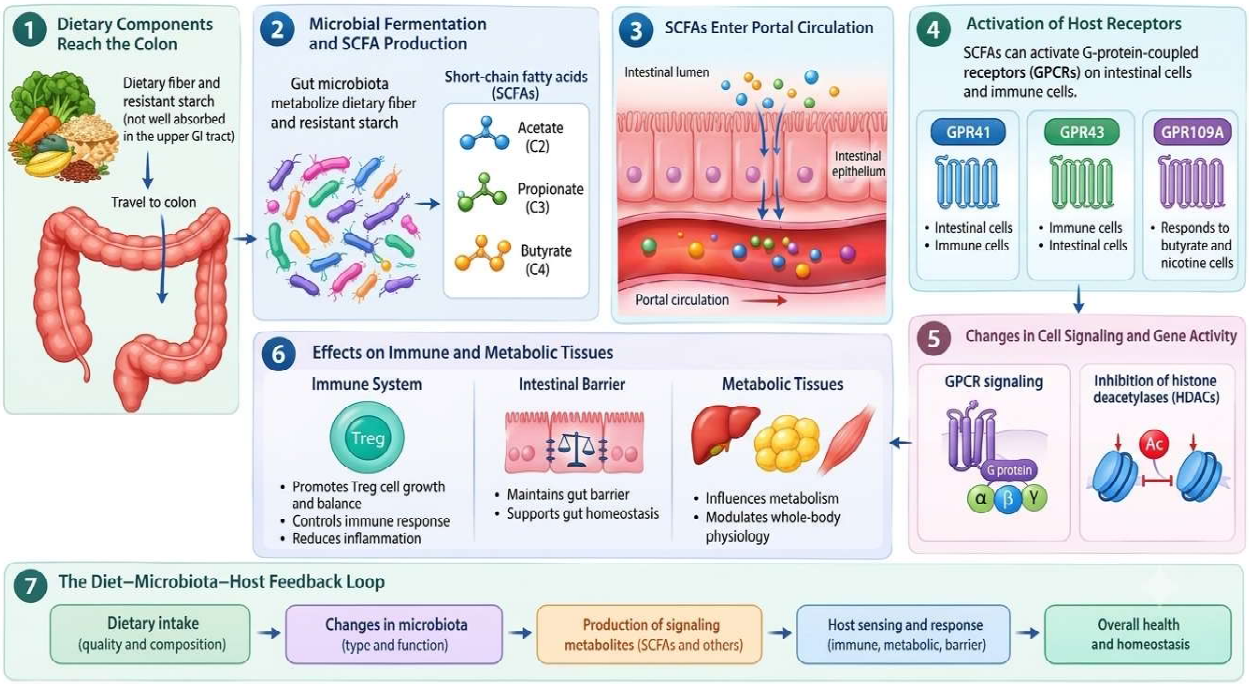


Fig. 1: Phases of Diet Gut Microbiota Host Communication: From Fermentation of Dietary Fiber and SCFA Generation to Regulation of Immune Metabolic and Intestinal Barrier Functions. 1) Nutritional Elements Arrive at the Colon. 2) Microbial Fermentation and Production of SCFAs. 3) SCFAs Access Portal Circulation. 4) Activation of Host Receptors. 5) Alterations in Cellular Signaling and Gene Function. 6) Impact, on Immune and Metabolic Tissues. 7) The Feedback Loop of Diet Microbiota and Host.

gut bacteria every day. Nutrients alone aren't the thing. The overall pattern of what we eat is more important. A mix of carbs, proteins, fats, fiber, vitamins and plant compounds has an effect than any single nutrient, by itself. Eating different foods helps keep the gut bacteria stable and healthy. The Western way of eating which has a lot of sugar, salt and bad fats is linked to health problems. It also changes the gut bacteria. Eating much fat, especially saturated fat changes certain bacteria. It might lower the amount of Bacteroidota. This way of eating helps the gut bacteria stay healthy. It also helps with body functions and brain function (Thomas et al., 2022; Zhang et al., 2024; Asnicar et al., 2021; Aron-Wisnewsky et al., 2021).

Carbohydrates have an effect on microwave activity inside the body. We see how carbohydrate such a sugar like fructose and sucrose can change the kids of bacteria that live here. Indigestible dietary fibre are very important for the microbes that live in the colon. This fibre come from fruits and vegetables. This fibre content part like fructo-oligosaccharides, galactooligosaccharides, inulin and pectins. Microbes break them down which changes the inside of the intestines. These fibers can act as prebiotics. They help good microbes grow and work better. Short chain fatty acids help keep the gut healthy help the body use energy and support systems. The amount of these carbohydrates changes the kinds of microbes. What they produce. Protein also changes the microbes. Where the protein comes

from matters a lot. We notice eating plant based proteins is linked to good microbes more short chain fatty acids and more branched chain amino acids. For example pea protein helps make short chain fatty acids that fight inflammation and keep the gut lining healthy. Animal protein quickly changes the microbes. It encourages Bacteroides that break down protein. Eating animal protein is linked to the presence of *Alistipes* and Bacteroides in some people. Diets high, in animal fat can lead *to Bilophila wadsworthia*, a bacterium linked to inflammation. Some fatty acids make it to the colon. There they meet the bacteria that live there. The kind of fat and how much we eat seem to shape how these bacteria react. Studies show that saturated fats can lower the variety of bacteria in the gut. They also reduce the number of bacterial groups. In animal studies such diets were linked to a bacterium called *Akkermansia* (Thomas et al., 2022; Zhang et al., 2024; Nogal et al., 2021; Rai et al., 2025).

Some gut bacteria can turn cholesterol into coprostanol. This shows how microbes break down what we eat and how this affects how body handles fats. This shows that food and microbes have a two way connection. When we take vitamin supplements, the kinds and numbers of bacteria, in the tract can change. That shift might cause inflammation in the intestines. Getting micronutrients helps keep a strong group of microbes alive. A healthy microbe community makes digestion easier. Fermented foods offer a way to change the inside of the body. Foods like yogurt, kefir, fermented soy, kimchi and sauerkraut can carry living things or the things those tiny living things make. This back-and-forth relationship might explain how eating plants affects metabolism the system and brain functions. Ultra-processed foods and the things added to them are another part of the world. These foods often have emulsifiers, preservatives and artificial sweeteners (Thomas et al., 2022; Zhang et al., 2024; Rabbani et al., 2025; Schneider et al., 2024).

MICROBIAL METABOLITES AND METABOLIC REGULATION

These are made when bacteria in the gut break down foods that the body can't digest and other materials from the body in the colon. Different types of bacteria make amounts of SCFAs. Also when bacteria work together like one bacteria feeding off another this helps the activity in the gut. Bacteria that make butyrate, like *Roseburia*, *Eubacterium*, *Anaerostipes* and *Faecalibacterium prausnitzii* are very important for keeping the gut healthy. Butyrate gives energy to the cells in the colon. Helps keep the lining of the gut strong. So if the mix of bacteria changes or if the food available changes the amount of SCFAs made can change. This can affect how the body works metabolically. SCFAs affect the body in two ways. They can work through receptors. Acetate, propionate and butyrate can turn on G-protein-coupled receptors. These include GPR41, GPR43. Gpr109a. These receptors are found in cells that line the gut in cells that make hormones in fat tissue in immune cells and other places that are important for metabolism. Also SCFAs can stop enzymes from working. This helps change how genes are used in the body. This is a way that the bacteria, in the gut can affect the way the body's genes work. In studies higher SCFA levels have been linked to glucose control feeling full and fat management. SCFAs boost the release of GLP 1, which helps the pancreas make insulin and keeps blood sugar steady. PYY also helps the body balance glucose and

energy. SCFAs further affect how fat is broken down and how fat cells shrink using pathways that involve the enzyme AMPK, the protein PGC 1á the receptors PPARs and the hormone leptin. When the gut becomes leaky bacterial parts such, as lipopolysaccharide (LPS) can enter the bloodstream causing a state called metabolic endotoxemia. This can activate the body's system slightly which is closely linked to metabolic syndrome, insulin resistance and type 2 diabetes (Nogal et al., 2021; O'Riordan et al., 2022). The link between metabolism and inflammation is important in how the body controls metabolism. Even a little bit of inflammation can make it harder for insulin to work properly.

This can mess up the way the body uses energy. When LPS, which means lipopolysaccharides, moves from the gut into the blood it can activate a receptor called TLR4. This activation causes the body to make substances such, as TNF-alpha, IL-1 beta and IL-6 in tissues that're part of the metabolism process. This inflammatory process can make it harder for insulin to work properly in the liver, fat tissue, muscles and in the cell that make insulin in the pancreas. They also change how cells behave. SCFAs help control how T cells develop and manage the release of substances. When there is inflammation, the way the body breaks down tryptophan might change leading to kynurenine and other substances that affect the immune system or the brain. These pathways are very important in type 2 diabetes. In this condition dysbiosis is linked to a mix of microbes, lower butyrate and other SCFAs a weakened gut barrier and more bacterial byproducts, in the body. Evidence shows that as microbes shift SCFA levels drop, metabolic endotoxemia rises, inflammation. Insulin resistance worsens. When beneficial SCFA producing bacteria go down the gut barrier gets weaker. The usual help that SCFAs give to metabolism and inflammation is reduced (Scheithauer et al., 2020; De Vos et al., 2022; Aron-Wisnewsky et al., 2021).

GUT–BRAIN AXIS AND NEUROINFLAMMATORY SIGNALING

The gut brain axis is a two way communication system. The gut brain axis links the gut microbiome, the nervous system, the endocrine system, the immune system and the central nervous system. The link between bacteria and the brain expands the idea of the gut brain connection. Bacteria can affect these nerve signals without talking. Another important route involves the barrier. When the barrier, in the intestine becomes more porous, bacteria or parts of bacteria may enter the body. This can lead to inflammation throughout the body. Cytokines, proteins released during reactions can move through the blood. Reach the brain. Inside the brain cytokines can impact cells. These cells help keep the brain healthy and working properly. The blood–brain barrier is a part of this system. It controls what can move between the bloodstream and the central nervous system. The barrier's health decides how molecules and immune signals pass through. Microbial metabolites can affect how the blood–brain barrier works by changing the function of endothelial cells and the pathways involved. At the time inflammation in the body can weaken the barrier. Because of this changes in gut bacteria metabolism have been studied as a reason for brain problems linked to long-term inflammation. Affect how the immune system functions. Since cells, intestinal epithelial cells and nerve-related cells all have pathways that respond to tryptophan metabolites changes in how gut microbes process tryptophan could

affect communication between the brain and immune system. In a way secondary bile acids can act through receptors that are involved in metabolic and immune signaling. These bile acids may also help mediate communication, between the gut and the nervous system. Short-chain fatty acids have gotten a lot of attention when it comes to brain inflammation. Butyrate and other short-chain fatty acids can affect how immune cells develop how T-cells respond, how the body adds acetyl groups to proteins and how inflammation happens. These changes might affect the brain by lowering inflammation in the body and keeping the gut strong. Short-chain fatty acids are not always "anti-inflammatory", in every situation. Their effects change depending on how much's there which part of the body its in, which receptors are active the body's energy use and the type of disease that is present. (O'Riordan et al., 2022; Schneider et al., 2024).

Neuroinflammation has been looked into in brain and mental health conditions. Changes in the gut bacteria and the substances they create have been found in Alzheimer's disease Parkinson's disease, depression, anxiety, multiple sclerosis and several other disorders. In Alzheimer's disease research has explored how gut barrier problems, body-wide inflammation, microbial products amyloid-related changes and activation of microglia may be connected. In Parkinson's disease scientists have studied how shifts in gut microbes relate to á-synuclein behavior gut inflammation, the vagus nerve pathways and symptoms, in the brain. Nevertheless it is important to be careful when looking at these results. The illness itself

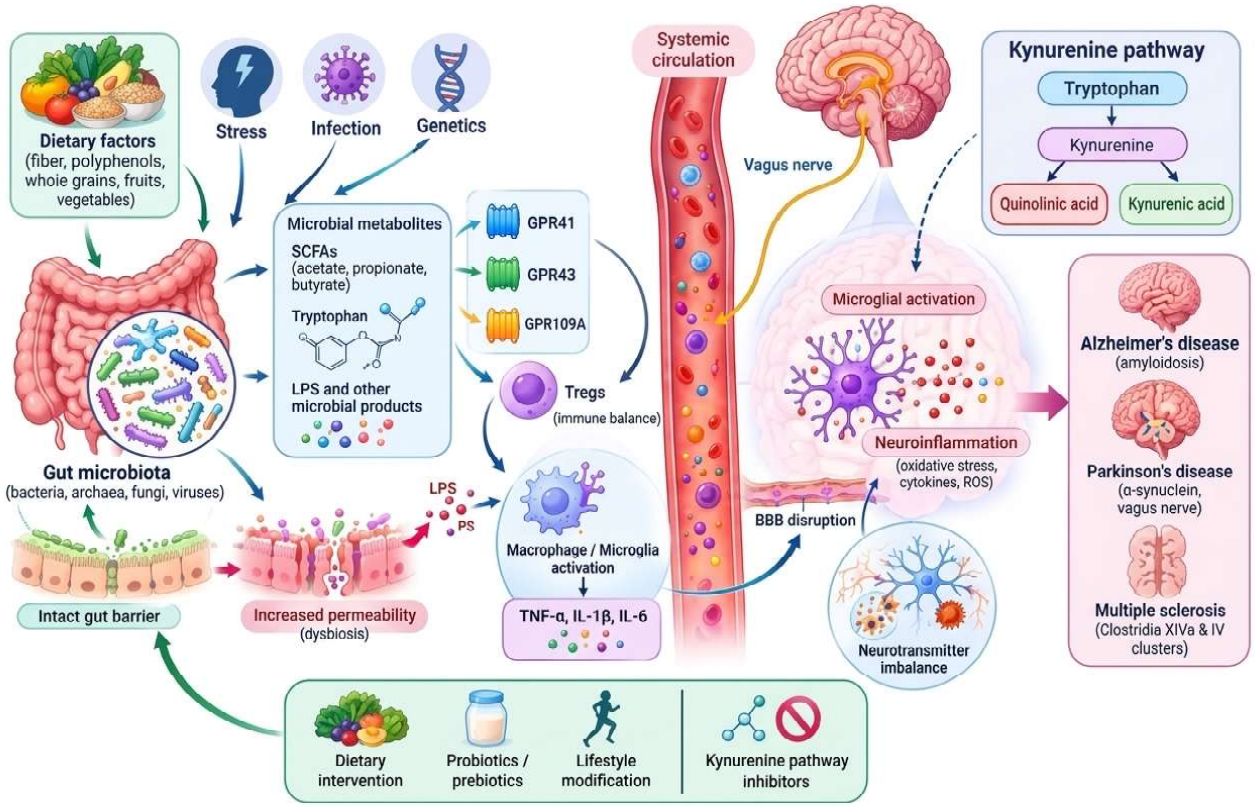


Fig. 2: The way the bacteria in our gut work the products they make the signals from our immune system and the connection between the gut and the brain all play a role in controlling inflammation, in the brain and keeping the brain healthy.

can change what someone eats how the intestines move, the medicines they take how much they. The types of microbes, in the gut. So a different microbiome seen in a brain-related condition could be part of the problem a result of the condition or both. Now there is evidence that makes sense biologically and shows important links but many cause-and-effect relationships are still being studied, especially in people (Bairamian et al., 2022; Fan et al., 2023; Schneider et al., 2024).

DYSBIOSIS IN METABOLIC AND NEUROLOGICAL DISORDERS

Dysbiosis means a change in the balance of microbes inside the body. It can mean there are types of microbes or fewer types than usual. It might also mean the microbes are acting differently than they should. This change messes up the relationship, between the body and the microbes. Dysbiosis is not one disease. There is no one definition that covers all cases of a microbiome. It can mean some microbes are missing or not doing their jobs. It could also mean the microbes are producing substances. Sometimes it means the whole microbial community is less stable. It could mean more microbes that cause inflammation are growing. Looking at what the microbes do is important. Simply counting them or labeling them does not always reveal what truly occurs inside the body. High levels of LPS exposure and metabolic endotoxemia have been studied as ways that dysbiosis might lead to low grade inflammation. The TLR4/NF êB pathway can start responses. Help produce cytokines, which might affect insulin signaling and how fat tissue behaves. Other pathways include altered SCFA production, bile acid signaling and the control of gut hormones. Because people take medicines like metformin, their body weight and how well their blood sugar is controlled all affect the bacteria it is hard to know what causes what (Aron-Wisnewsky et al., 2021; Scheithauer et al., 2020; De Vos et al., 2022; Thomas et al., 2022; Sasidharan Pillai & Ashraf, 2026).

The connection between microbiota and metabolic diseases is also very important for the liver (Aron-Wisnewsky et al., 2021). The liver and the intestine are connected through the bloodstream. This allows microbial metabolites and other substances to reach the liver tissue. Changes in the intestines ability to act as a barrier might increase the liver's exposure to materials. This could play a role, in causing inflammation and metabolic issues seen in metabolic dysfunction-associated steatotic liver disease. Bile-acid metabolism is another way the liver and the gut communicate. Neurological diseases share a relationship that's just as complex. Research on Alzheimer's and Parkinson's diseases has found shifts in gut makeup and its products yet I see that results vary widely. These changes involve pathways that include IL 17, regulatory T cells and other immune messengers. When bacteria in the gut act differently the balance of the immune system can shift and that shift might change how inflammation in the brain happens. The connection, between dysbiosis and neuroinflammation might also include metabolic inflammation. Because of this the gut microbiota could be one part of a system that links food, fat tissue, immune responses, blood vessel health and brain function (Bairamian et al., 2022; Agirman et al., 2021).

NUTRITIONAL STRATEGIES FOR MICROBIOTA MODULATION

Dietary approaches focus on fiber, probiotics,

plants-based foods, polyphenols, vitamins and minerals to support the gut microbiome. Choosing these foods helps boost the barrier's function supports immune responses and encourages the production of microbial metabolites. This can lead to metabolic health and less inflammation, through gut-brain communication (Table 1).

PRECISION NUTRITION AND PERSONALIZED MICROBIOME INTERVENTIONS

Precision nutrition is more than giving advice about food. It looks at the traits that every person has. This is because the gut microbiome is very different for every person. It can also change depending on what we eat. The same

Table 1: Nutritional Approaches to Change the Gut Microbiota.

Nutritional strategy	*Main dietary components/examples*	*Effect on gut microbiota*	*Potential metabolic/ immune relevance*	*Reference*
Dietary fibre	Soluble and insoluble fibre, resistant starch	Helps with fermentation and production of SCFA	Helps with the intestinal barrier, immune regulation and metabolic health	Dasriya et al., 2024; Stewart et al., 2008
Prebiotics	Fructooligosaccharides (FOS),GOS, insulin.	Stimulate beneficial bacteria, particularly Bifidobacterium	Supports microbial balance and intestinal health	Stewart et al., 2008
Plant-based diet	Fruits, Vegetables, Legumes, whole grains.	Can promote favourable microbial communities	May reduce intestinal inflammation and metabolic risk	Kim et al., 2013
Mediterranean diet	Plant foods, fibre, olive oil, fruits and vegetables.	Supports a diverse and beneficial microbiota	Associated with metabolic and immune benefits	Barrea et al., 2021
Polyphenol	Pomegranate, green tea, berries and other plant foods.	May increase beneficial bacteria such as *Bifidobacterium* and *Lactobacillus*	Antioxidants and potentially anti-inflammatory effects	Santhiravel et al., 2022
Dietary fats	Olive oil, fish derived omega-3 fatty acids and other unsaturated fatty acids	Different fats can produce different microbial responses	May influence inflammation and intestinal health	Dasriya et al., 2024
Probiotics	*Lactobacillus*, *Bifidobacterium* and selected items.	Introduced beneficial microorganisms and influence microbial balance	May modulate immune and inflammatory responses	Dasriya et al., 2024
Vitamins and minerals	Vitamins, zinc, iron and other micronutrients.	Support microbial and host metabolic functions	Important for intestinal barrier and immune function	Dasriya et al., 2024
Limit highly processed foods\ additives	Excessive emulsifiers and some artificial sweeteners	Some additive may alter microbial composition	May induce intestinal inflammation	Chassaing et al., 2017

meal can cause blood sugar to rise in one person. In another person it might remain steady. The combination of gut microbes and how they function helps explain these differences. Scientists try to determine which people will benefit from diets. They do this by bringing together information about the gut microbiome with data, on health, diet, metabolism and genetic factors. This new approach changes the question from whether a food's good or bad overall. In gut bacteria and how they work can strongly affect how the body reacts to food. They send signals that influence the body's metabolism. The food we eat such as carbohydrates, proteins, fats and fiber can change both the kinds of gut microbiome and what they do. Every person has a mix of gut microbes. That mix can change how a person reacts to foods or diet plans. This shows a link, between what we eat and the gut microbiome. They influence each other (Asnicar et al., 2021; Zhang et al., 2024; Thomas et al., 2022; Li et al., 2026).

This might lead to more personal health plans. Managing metabolic health especially the differences in post meal glucose responses. We find this area fascinating because predicting and managing metabolic health helps people keep their blood sugar in check (Li et al., 2026; Sasidharan Pillai & Ashraf, 2026; Rai et al., 2025). Research, in precision nutrition shows that microbiome information can help predict how each person will react to foods. Microbiome information is part of a complex biological system. Genes, what people eat every day their age the way they live medicines they take and many environmental factors all play a role, in how the body responds. Because many things influence health personalized nutrition should be seen as a broader strategy. It should not just focus on the microbiome. However making sure results can be repeated handling the fact that every person's different setting up standard ways to measure things dealing with how data is managed and proving that these methods work in real medical settings are still big problems. These issues need to be solved before such methods can be used regularly (Asnicar et al., 2021; Wang et al., 2024; Nogal et al., 2021; Li et al., 2026; Zhang et al., 2024).

PUBLIC HEALTH AND TRANSLATION CHALLENGES

The more people learn about the gut microbiota as something that helps control health, the immune system and brain inflammation the more chances there are for public health and personal nutrition plans. Turning microbiome research into real food advice and medical treatments is still hard. The mix of bacteria in the gut and what they do changes a lot from person to person because of food, genes, age, how they live, medicines they take where they live and what they are exposed to. So the same food plan can cause body reactions in different people. This difference, between people makes it hard to create one-size-fits-all nutrition advice based on the microbiome. A big problem in research is that there is no method and no reproducible results. Many steps in the process can change the results. This includes how food intake is measured, how samples are collected and stored how DNA is extracted, which sequencing machines are used which bioinformatics tools are chosen (De Vos et al., 2022; Zhang et al., 2024; Asnicar et al., 2021; Li et al., 2026).

These methodological worries matter when microbiome biomarkers are used to predict diseases like diabetes, obesity, heart risk or brain

inflammation. If the techniques are not reliable then any predictions, from the techniques may not be accurate. This means research must fix the basics before research can trust diagnostics or treatments that rely on the microbiome (De Vos et al., 2022; Asnicar et al., 2021; Li et al., 2026; Sasidharan Pillai & Ashraf, 2026).

CONCLUSION

Recent research from PubMed shows that the gut microbiota is very important in linking what we eat to how our body manages energy how our immune system works and how our brain functions (Asnicar et al., 2021; Schneider et al., 2024). The bacteria in the gut change the food we eat into substances like short-chain fatty acids altered bile acids and parts of acids (Nogal et al., 2021; O'Riordan et al., 2022). These substances can influence how the body handles sugar and fat how strong the gut barrier's how well the immune system works and how the gut and brain talk to each other. When the balance of these gut bacteria becomes disturbed—this is called dysbiosis—it has been connected to weight gain, insulin resistance, problems, with type 2 diabetes how the body uses energy and lasting low-grade inflammation.

Data shows a link between diet, gut microbiome and neuroinflammation (Schneider et al., 2024). We think this means that changes in the gut microbiome or its chemicals can influence how well the gut wall stays intact how the body sends signals how the blood–brain barrier behaves and how the immune nervous, hormone and metabolic systems communicate. This points again to a connection, among diet gut microbiome and neuroinflammation (Trisal et al., 2025; Kumari et al., 2026).

In general We believe a varied and balanced gut microbiome is essential, for metabolic and neurological health (Aron-Wisnewsky et al., 2021; Schneider et al., 2024). Diets rich are in dietary fibre and plant-derived foods may support beneficial microbial functions. Whereas as Western-style dietary patterns characterized by high amounts of fat and refined or ultra-processed foods and low fibre are associated with dysbiosis and inflammatory changes (Zhang et al., 2024; Rai et al., 2025). Nevertheless many important findings are still coming from experiments or observations (Asnicar et al., 2021; Li et al., 2026). How people react to changes in their diet and their gut bacteria is very different from one person, to another. Studies that come after this should therefore look at clinical trials that are well organized checking the microbiome over a long time and diets that are made just for each person. Studies that come after this should therefore look at clinical trials that are well organized checking the microbiome over a long time and diets that are made just for each person. These methods might help turn research into real plans, for stopping or dealing with metabolic disorders and neuroinflammatory problems (Rabbani et al., 2025; Sasidharan Pillai & Ashraf, 2026; Kumari et al., 2026).

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