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The Role of Diet–Microbiota Interactions in Metabolic and Neuroinflammatory Disorders: Public Health Perspectives

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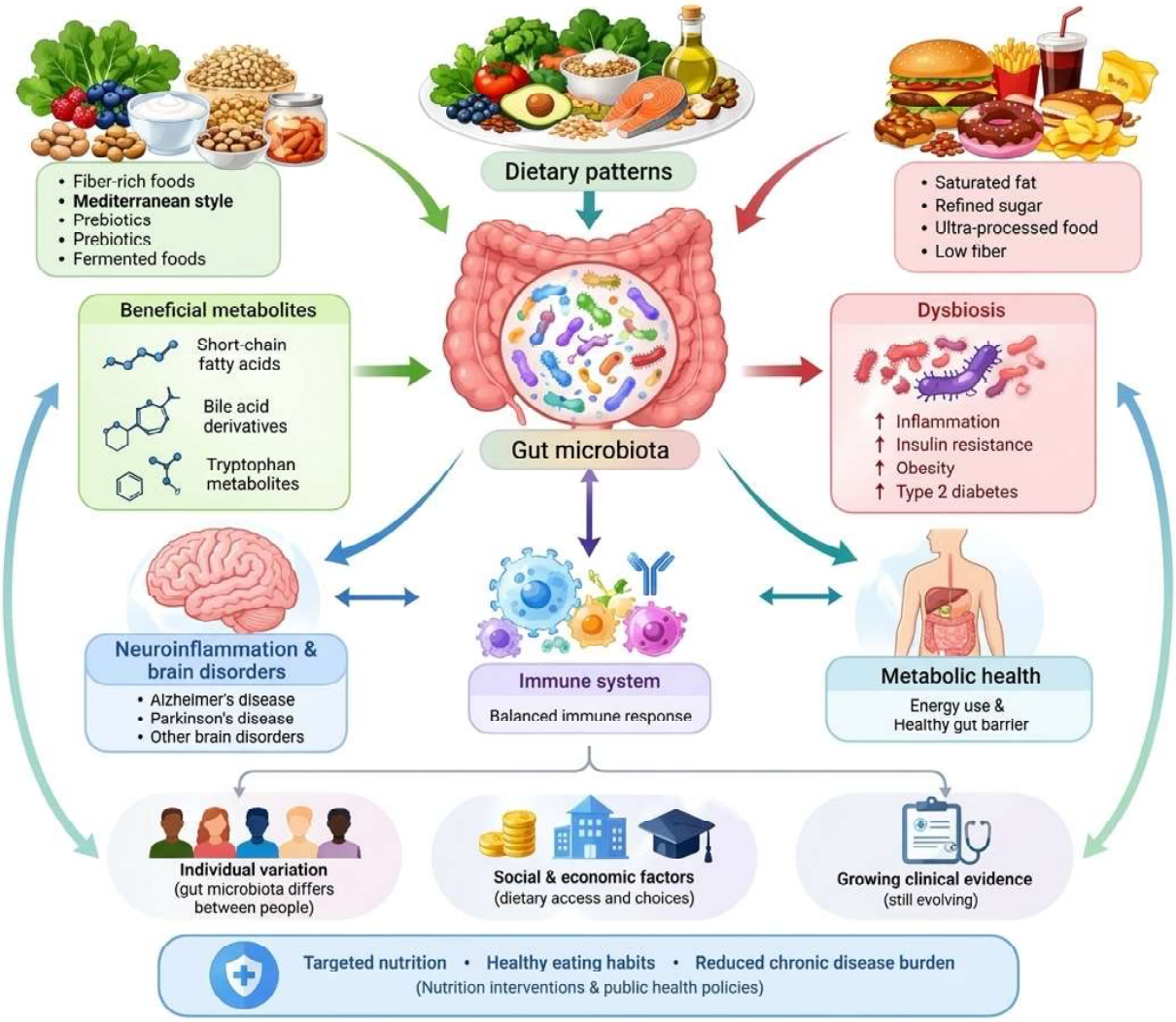
ABSTRACT

Gut microbiota in humans is very important to keep the balance of our metabolism, immune system and the health of our brain. Growing evidence indicates that our eating patterns, or how we eat, interact with the gut microbiota to influence the development and progression of metabolic disorders and neuroinflammatory conditions. The microbes living in the gut, their abundance and their functions are determined by the diet we choose. The microbes generate compounds like chain fatty acids, derivatives of bile acid and tryptophan metabolites. These compounds help our body to utilise energy, maintain the integrity of the gut lining, protect our system and enable communication between the gut and the brain. Too much saturated fat, sugar or ultra-processed food and not enough fibre can unbalance the gut microbiota. This imbalance can lead to low-grade inflammation, insulin resistance, obesity and type 2 diabetes. New research also connects changes, in the gut microbiota to neuroinflammatory processes that may be part of Alzheimer's disease Parkinson's disease and other brain disorders. On the hand foods rich, in fiber the Mediterranean style, prebiotics, probiotics and fermented foods can help the gut microbiota stay healthy and improve both metabolic and inflammatory outcomes. From a health point of view knowing how diet and the gut microbiota interact gives us chances to create preventive nutrition plans encourage healthy eating habits and lower the burden of chronic disease. We must remember that each person's gut microbiota is different that social and economic factors affect what people can eat and that the clinical evidence is still growing. This review looks at how diet, the gut microbiota, metabolic dysfunction and neuroinflammation reconnected and it shows how these ideas can guide nutrition interventions and public health policies.

Keywords: Gut microbiota; Metabolic disorder; Dietary pattern; Dysbiosis; Public health nutrition; Prebiotic and probiotics; Short chain fatty acids



Graphical Abstract

INTRODUCTION

The human gut microbiota includes trillions of organisms like bacteria, viruses, fungi and other microbes that live in the digestive system (Asnicar et al., 2021). These tiny creatures are very important for keeping people healthy. They help with digestion control how the body uses energy make vitamins help keep the inside of the gut strong and affect how the immune system works. In years scientists have found more and more about how what people eat interacts with the gut microbiota. This connection plays a role in causing and stopping many long-term illnesses (Wastyk et al., 2021). What people eat changes the types and activities of the microbes in the gut. At the time the microbes in the gut change how the body uses food and how the body works. So learning more about how eating and the gut microbes interact's very important for understanding health problems related to metabolism, brain function and public health. What people eat is one of the things that shape the gut microbes. A diet that has lots of fiber, fruits, vegetables, whole grains, beans and other plant foods can help the gut have different kinds of microbes. These microbes break down fiber (Wang et al., 2021). Make short-chain fatty acids. These fatty acids help the gut stay healthy reduce

inflammation help control blood sugar and keep the gut strong. On the hand eating a lot of fats, sugary foods, processed foods and refined carbs can hurt the balance of the gut microbes. This kind of eating can lead to a gut, called dysbiosis. Dysbiosis has been linked to health problems like obesity, diabetes and other issues. These health problems are problems all around the world. Changes in the gut microbes caused by diet may affect how the body gets energy from food how hungry people feel, how sensitive the body is to insulin, how the body handles fats and how inflammation the body has. An unhealthy diet might make the gut more open letting parts of the microbes get into the blood and cause problems. Constant small inflammation and problems with how the body works can lead to long-term diseases. Even though research supports these links the connections are not simple. People have genes live different lives take different medicines and face different environments. All of these things also affect the chances of getting sick. Besides health problems related to metabolism what people. The gut microbes can also affect the brain. This is called the gut–brain axis, a way that the gut and the brain talk to each other. This talk happens through nerves, immune messages, hormones and chemicals made by the microbes. The gut microbes can change how the body makes and controls chemicals that help the brain work. They can also change the system and how the body deals with inflammation. Changes in the gut microbes have been linked to brain problems like sclerosis, Parkinson's disease and some mental and mood issues (Cronin et al., 2021). Eating in a way that helps the gut stay balanced may help control inflammation and keep the gut and brain talking. More research is needed to understand exactly how this works and what benefits it can bring. From the health point of view the link between what people eat the gut microbes and long-term illness shows how important it is to eat healthy and live well. Programs that encourage people to eat healthy fiber-filled foods may help improve health and support brain function. Public health efforts like teaching people about food offering advice on what to eat making food policies and making healthy foods easier to get can help lower the number of diseases caused by poor eating. Research into bacteria things that feed good bacteria foods that are fermented and eating for each persons needs may also offer chances to help prevent and treat diseases. In conclusion what people eat and the gut microbes are important for nutrition how the body uses energy, how the immune system works and brain health (David et at., 2021).

DIET, MICROBIOTA AND HUMAN HEALTH

Diet and the gut microbiota are tightly (Choi et al., 2021). Both play a very important role in keeping people healthy. The gut microbiota is made up of trillions of living things, such as bacteria, archaea, fungi and viruses that live inside the gut. These tiny living things are constantly interacting with the food we eat and with our bodies. They help with digestion, metabolism, the immune system and overall body health (La Torre., 2021). Diet is one of the things that shape the gut microbiota, its variety and how it works. When a diet is rich in fibre, whole grains, fruit, vegetables, beans, nuts and other plant foods it gives good gut microbes the food they need to ferment (Croci et al., 2021). This fermentation makes short chain fatty acids (SCFAs) like acetate, propionate and butyrate. These SCFAs help keep the gut lining control immune reactions influence how the body uses sugar and fat and can help keep inflammation low (Gutierrez et

al., 2021). Butyrate for example is a fuel for cells in the colon and helps keep the gut lining healthy. On the hand diets that are high in saturated fat refined sugars, processed foods and low in fibre can change the gut microbiota and reduce its variety. These changes, called gut dysbiosis have been linked to problems with metabolism and inflammation. The effects can be different from person to person. For instance polyphenols found in fruit, vegetables, tea, cocoa and other plant foods can be turned by gut microbes into substances that have effects. Likewise gut microbes help to transform bile acids and to produce active substances which facilitate communication of the gut with other organs. The gut microbiota also interacts with the immune system and helps to maintain its homeostasis. A healthy and diverse microbial community can contribute to the development of the immune system and its protection against the invasion of pathogens. The gut–brain connection, where gut microbes affect the system may also influence mood and behavior through microbial chemicals, immune signals and nerve pathways. Because of this scientists have looked at how diet and gut microbiota affect conditions like obesity, type 2 diabetes, heart disease, inflammatory bowel disease and other long term illnesses. However how the gut microbiota responds to diet can be very personal. Depends on genetics, age, lifestyle, medicines and existing health problems (Ray et al., 2021). In short eating a nutrient rich diet with plenty of fibre can help keep the gut microbiota diverse and active making the study of diet and gut microbiota a key area, for understanding and promoting human health.

DIETARY DRIVERS OF GUT DYSBIOSIS

The gut has a balance of living things inside it (Medawar et al., 2021). This balance can change when the types or amounts of these things are not right. One of the things that can change this balance is what you eat. What you eat gives food to these things that live in your stomach and intestines (Knudsen et al., 2021). A diet that has a lot of processed foods, foods that are not healthy and not much fiber can make the tiny things in your gut change in a bad way. Fiber comes from fruits, vegetables, whole grains and other healthy foods (Perez et al., 2021). These tiny things in your gut like to eat fiber. When they do they make some helpful things called short-chain fatty acids. These things help the gut stay strong help the body's defense system and help keep the body's energy system working right (Attaye et al., 2022). If you don't eat fiber the tiny things don't have enough to eat. This can make less of these things. If you eat a lot of foods that're high in bad fats this can change the way the body makes something called bile acids. This change can make some tiny things grow more than others and cause problems. Eating a lot of sugar can also change what kinds of things are in your gut. It can make some grow quickly. Others disappear. Eating a lot of meat can also change the things in your gut. This is because there is protein and other things for them to eat. Some of the things these tiny things make when they eat protein can be bad for the gut. Some things in processed foods like some of the things that help keep food fresh or make it taste better may also affect the things in your gut. How much of these things you eat and what kind they are can change the effect on your gut. If you eat healthy foods like fruits, vegetables and foods that have been made to have more tiny things you can help the tiny things in your gut stay healthy. These foods give the things different things to eat. Some of these things like polyphenols can help certain tiny things grow more than others. The way

food changes the things in your gut can be different for each person. Things like age how you live what medicine you take, where you live and what health problems you have can change what happens. If you change what you eat for a time it can change the tiny things in your gut. If you eat a way for a long time it can change them more. So the way food affects the things in your gut is not just about individual foods. It's about the quality of what you eat how many different kinds of food you eat and your eating habits, over time. Learning about this is important to help keep your gut healthy and to avoid problems that come from eating (He et al., 2021).

MICROBIOTA AND METABOLIC DISORDERS

The human gut microbiota is a group of bacteria, archaea, fungi, viruses and other tiny organisms. This community plays a role in keeping metabolic health in balance (Howard et al., 2022). These microbes help with digestion break down nutrients support the system protect the lining of the gut and produce active substances that affect the body. Over time more studies have shown that changes in the makeup and activity of these gut microbes. Often called gut dysbiosis (Thomas et al., 2022). Are linked to metabolic problems. These include obesity, type 2 diabetes, metabolic syndrome, -alcoholic fatty liver disease (NAFLD) and heart disease. A healthy gut microbiota makes compounds like short-chain fatty acids or SCFAs. The common ones are acetate, propionate and butyrate. These are produced by gut bacteria that break down dietary fiber from plants. Many of these fatty acids influence the body's ability to balance blood sugar levels, control hunger and satiety hormones, as well as maintain the integrity of the gut barrier and reduce inflammation. Butyrate, in particular, provides fuel for the cells lining the gut and supports their integrity and barrier function. When dysbiosis happens the good bacteria may. Harmful microbes may grow. This can lead to increased inflammation and impaired control of metabolism (Xu et al., 2022). In obese individuals, changes in the composition of intestinal bacteria have been noted that are associated with increased energy harvesting from food. They also affect bile acid processing weaken the gut barrier and cause low-level inflammation. When the gut becomes permeable harmful bacterial parts like lipopolysaccharide (LPS) can leak into the blood. This contributes to inflammation and insulin resistance. In type 2 diabetes researchers have found differences in the number and types of gut bacteria. These alterations often occur along with impaired control of blood sugar levels and a decrease in the body's sensitivity to insulin. The microbiota also participates in modifying bile acids. The activity of microbes changes the composition of these acids, which affects the metabolism of carbohydrates and lipids by acting on specific receptors like FXR and TGR5.Another substance produced by intestinal bacteria called trimethylamine N-oxide or TMAO accumulates in the body due to the breakdown of carnitine and choline from food by microbes. TMAO has become a focus in studies on heart and metabolic health. In -alcoholic fatty liver disease (NAFLD) an imbalanced gut microbiota might affect fat buildup in the liver promote inflammation damage the gut barrier and change how microbial metabolites are produced (Bliensner et al., 2022). These changes could accelerate the natural history of the disease. The diet affects the composition of the microbiota. The diet that is abundant in fiber

(vegetables and fruits) and includes whole grains, legumes, and other dietary fibers provides nutrients for microbes. On the hand diets high in ultra-processed foods saturated fats and added sugars can create a less favorable environment for good bacteria if eaten too much. The connection, between gut microbes and metabolic diseases is not simple. It depends on genetic age, drugs, lifestyle choices, and other factors. Scientists are now focusing on manipulating the gut microbiota to improve a person's health. They are now working on approaches that include the addition of fibers in the diet, prebiotics, probiotics, fermented foods, and individualized diets (Fu et al., 2022). The comprehension of the interactions between diet, microbiota, metabolites, and host physiology will contribute to the development of strategies for the prevention and treatment of metabolic diseases.

MICROBIOTA, GUT–BRAIN AXIS, AND NEUROINFLAMMATION

The microbiota gut brain axis is the communication pathway between stomach and brain. It connects the stomach region, the living things in the gut, the defence system of the body, the system which makes hormones and the brain (Bostick et al., 2022). The stomach is home to trillions of living things including bacteria, other small organisms, fungi and viruses. These tiny living things help the stomach area work and they also affect how the brain works in several different ways (Fig. 1). The tiny living things in the gut make chemicals, particularly short-chain fatty acids such as acetate, propionate and butyrate. They can change how the body's defence system works, how the walls of the stomach stick together, how brain chemicals work and how brain cells act (Gates et al., 2022).

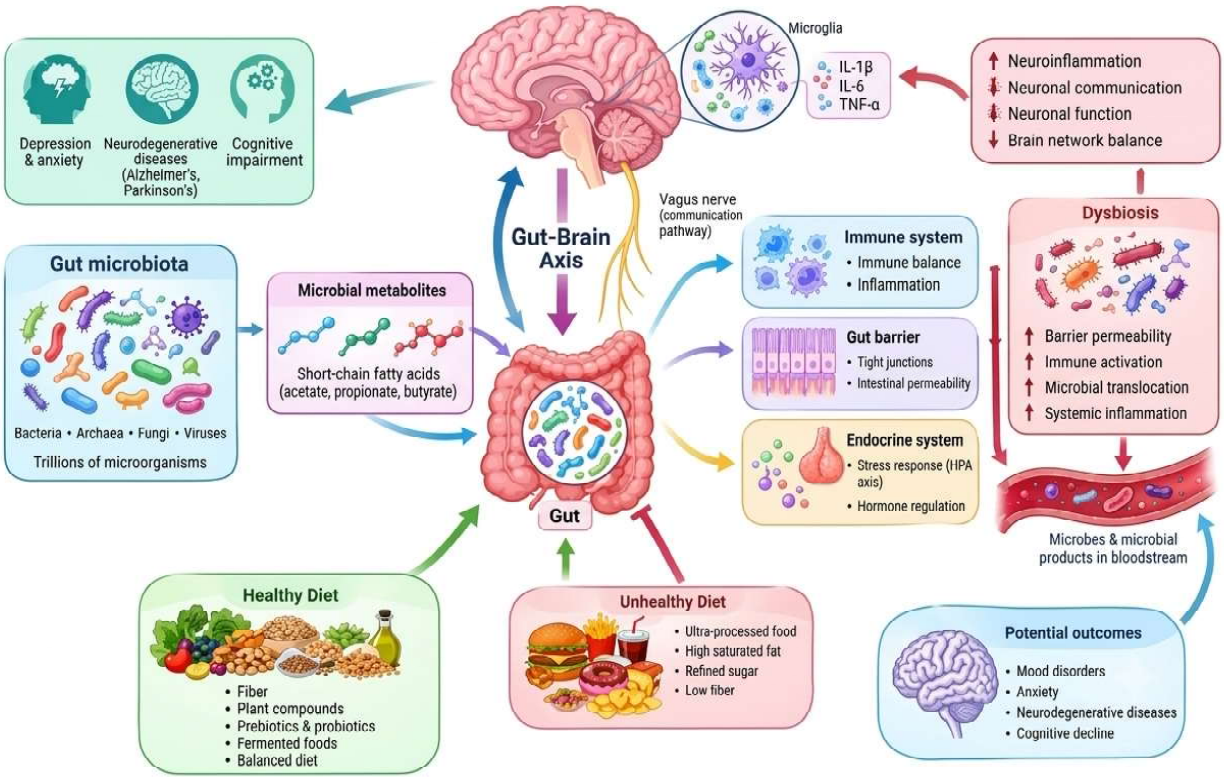


Fig. 1. Dite-Gut microbiota-Brain Axis and its Role in Neuroinflammation and neurodegenerative disorders.

The tiny living things in the gut also talk to the vagus nerve, which's a main way the stomach and the brain send messages back and forth. Also the tiny living things in the gut can change how the system that controls stress works and how the body reacts to stress (Horn et al., 2022). A healthy and different mix of living things in the gut usually helps the stomach walls work well and helps the bodys defense system work properly. When the mix of tiny living things in the gut is not right it can make the walls of the stomach more open and cause the bodys defense system to react too much. This can let tiny living things and signals from them get into the blood and possibly affect the brain and nervous system. One big result of this is inflammation in the system. The chemicals made by the living things and the signals from the bodys defense system can change how the brains defense cells work (Fairely et al., 2022). Normally these brain defense cells watch over the brain. Help it stay healthy but if they are always active they can start to cause more inflammation and make more chemicals like interleukin-1â, interleukin-6 and tumor necrosis factor-á. Lasting inflammation in the brain has been linked to problems with how brain cells talk to each other how they work together and how the brain stays in balance. Scientists have looked into how changes in the living things in the gut might be connected to brain problems like depression, anxiety, brain diseases that get worse over time and trouble with thinking. These links are not simple and there is no proof that changes in the tiny living things in the gut alone cause these problems. On the hand eating a lot of food that has been changed a lot and not enough fiber can create a bad environment for the tiny living things, in some people. Learning more about the microbiota gut brain axis might help create ways to keep the stomach and the brain healthy through food tiny living things and other treatments (Lee et al., 2022).

NUTRITIONAL INTERVENTIONS AND DISEASE PREVENTION

Nutritional interventions are a part of preventing disease. They help improve the quality of (what people eat fix missing nutrients and strengthen the system (Varesi et al., 2022). In addition, these interventions cut down on the consumption of foods associated with long-term health issues. Having a diet that is rich in carbohydrates, protein, healthy fats, vitamins, minerals, dietary fibre and water is essential. This kind of diet supports growth energy use, tissue healing and the body's regular functions (Kimble et al., 2022). Consuming a diet that is rich in fruits, vegetables, whole grains, legumes, nuts, and seeds has a number of health benefits. They contain fibre, antioxidants, vitamins, minerals, and other beneficial substances. The fibre is indigestible and, therefore, it passes through the digestive tract undigested (Barber et al., 2023). It is needed for the normal functioning of the intestines and allows the growth of beneficial bacteria that live in the intestines. These bacteria break down fibre into short-chain fatty acids that are beneficial for the body: they affect the health of the intestines and metabolism (Fig. 2). Nutritional interventions are also useful in the prevention and management of obesity and metabolic syndrome. They encourage people to eat the amount of calories eat meals at regular times and avoid foods that are high in added sugars, saturated fats and too much salt. Keeping an eating pattern can help prevent and manage heart disease.

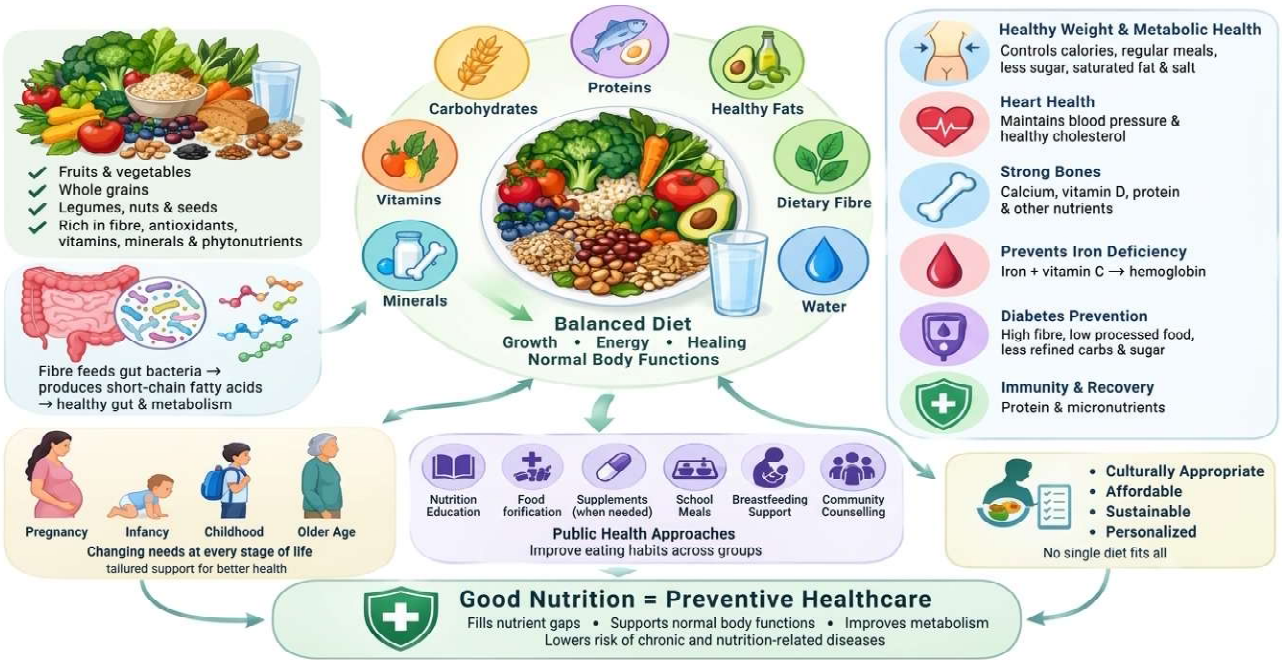


Fig 2. Components and Health Benefits of a Balance Diet

It helps to support blood pressure and cholesterol levels. Cutting down on salt and increasing one's intake of food with potassium may also help to reduce blood pressure levels. Calcium, vitamin D, protein and other nutrients contribute to the maintenance of healthy bones. Having enough of these nutrients help one to prevent bone deterioration and other bone abnormalities. Iron-rich foods, along with sources of vitamin C help prevent iron deficiency and support the formation of hemoglobin, which carries oxygen in the blood. Nutrition plays a role in preventing diabetes. They help the body fight infections and recover from illness (Gondogdu et al., 2023). Nutrition is especially important during stages of life. These include pregnancy, infancy, childhood and older age. Nutritional needs change as people grow and age tailored support is needed. Public health approaches like nutrition education adding nutrients to food supplements when needed, school meals, support, for breastfeeding and community nutrition counselling can help improve eating habits across groups. It's important that nutritional interventions fit the culture of the people they serve. They must be accessible, enduring over time and adapted to individual health needs. There is no universal diet that suits everyone's health needs. On the contrary, it is a personal project. In the end good nutrition is a part of preventive healthcare (Guan et al., 2023). It helps fix gaps supports the body's normal functions improves metabolism and lowers the risk of chronic and nutrition-related diseases

POPULATION-LEVEL EVIDENCE AND HEALTH DISPARITIES

At the population level, nutrition has been shown to be a major determinant of health, disease prevention and quality of life. Dietary patterns affect the prevalence of obesity, cardiovascular disease, type 2 diabetes, certain cancers, micronutrient deficiencies and other chronic diseases in populations (Liu et al.,

2023). Evidence from epidemiological studies, national nutrition surveys, and interventions demonstrate that the diet rich in fruits, vegetables, whole grains, legumes, nuts, seeds and fibre is commonly associated with better health indicators, while the consumption of ultra-processed food, added sugars, sodium and unhealthy fats are related to poorer health outcomes (Table 1)

IMPLEMENTATION CHALLENGES AND POLICY CONSIDERATIONS

The use of diet and gut microbiota to prevent long-term illnesses brings up problems that need to be fixed using teamwork between scientists, doctors, health workers and people in charge of making rules. One big problem is that the gut microbiota is very complicated and changes

Table 1: Population Level Evidence and Health Disparities

Key point	*Description*	*Reference*
Population health pattems	Large-scale studies shows that dietary, environmental, socioeconomic, and lifestyle factor influence health outcomes across populations.	Van Hul et al., 2023
Socioeconomic inequlities	Lower income population may experience greater exposure to unhealthy food environment and reduced access to nutritious foods and healthcare	Carmody et al., 2023
Dietary disparities	Differences in food availability, affordability, education, and cultural practices contribute to unequal dietary quality between population groups.	Kern et al., 2023
Chronic disease burden	Health disparities are reflected in unequal rates of obesity, diabetes, cardiovascular disease, and other chronic conditions among different communities.	Li Q et al., 2023
Gut microbiota differences	Population studies suggest that diet, geography, lifestyle, and socioeconomic conditions can influence gut microbiota composition and diversity.	Kleine et al., 2023
Urban-rural differences	Rural and urban populations may differ in healthcare access, food availability, sanitation, physical activity opportunities, and disease risk.	Zhang et al., 2023
Age-related disparities	Nutritional needs and disease risks vary across children, adults and older people, creating different patterns of health outcomes.	Hey et al., 2023
Healthcare access	Differences in healthcare availability, preventive services diagnostic facilities, and treatment can contribute to unequal health outcomes	Perler et al., 2023
Environmental influences	Pollution, sanitation, housing conditions, occupational exposures, and other environmental factors can interact with nutrition and lifestyle to affect population health	Deehan et al., 2024
Need for targeted	Population – level evidence supports culturally appropriate, affordable, and equitable public-health strategies designed to reduce preventable health disparities	(Ross et al., 2024)

from person to person (Ayten et al., 2024). The mix of bacteria inside a person can be different because of their age, family background, where they live how they live the medicines they take and what they eat. So a diet that helps one group of people may not work the same for another group. Another big issue is changing what is found in labs and on animals into something that works for humans. Even though studies show that what people eat, the germs in their gut the chemicals the germs make and health problems are connected we need long-term and well-run studies to show exactly how they are linked. Making sure everything is the same is also important because different ways of checking the microbiome ways of tracking what people eat different ways of collecting samples and different ways of looking at data can make it hard to compare results across different studies. From a real-life point of view following a diet can be tough because people like foods they have traditions they have different money situations the food they can get varies and not everyone knows much about healthy eating (Schneider et al . , 2024). Healthy meals can also cost more. Be harder to get for some people, which leads to unfair benefits from nutrition-based ways of stopping illness. So rules should focus on making healthy foods easier to get teaching more about nutrition and making recommendations that fit cultures. Government and health groups can make rules that push people to eat fruits, vegetables, whole grains, beans and other high-fiber foods while eating less processed foods, added sugar and bad fats. Rules about food labels, school food programs, local education about nutrition and support for making foods can help make better eating environments. Rules should also push for proper ways to make and control probiotics, prebiotics, special foods and other things that affect the microbiome so that the claims made about them are backed up by strong science. Keeping data safe and thinking about ethics is getting more and more important because microbiome studies involve a lot of genetic details. There need to be rules about collecting, keeping, sharing and using the data. Doctors should be trained well to explain what the science says about food and the microbiome. Not say things that are not proven. Finally putting things into action should involve checking how well it works how safe it is, how much it costs. If it helps everyone equally. Working together between scientists, doctors, people in charge of rules, food companies and local groups is needed to turn research about the microbiome and food into plans for health (Loh et al., 2025). A good set of rules that uses science makes things cheap fits with traditions has rules and gives access can help make the most of diet plans, for stopping illness in the long run.

FUTURE DIRECTIONS FOR PRECISION NUTRITION AND PUBLIC HEALTH

Precision nutrition is a way of thinking about food and health. It wants to give people advice about what to eat based on what makes them different (Xu et al., 2024). These differences can be in their genes how their body works the tiny creatures living in their gut how they live, where they live and how healthy they are. In the future precision nutrition could change how we take care of health for everyone. Of giving the same advice to all people it could offer more personal and better advice based on real science. These numbers can be put together using computers to make better eating plans and find people who may get sick from poor food choices. One big part of this future is using the creatures in the gut (Dalamaga et al.,

2024). These creatures can change how we feel how our body fights disease how we react to food and how we use energy. So changing what we eat to help these creatures may be a part of the future. We need more big studies with many people to make sure this works. Precision nutrition also needs to be easier for people, not just a few who can afford special testing or go to special places. Future work should focus on tools that're not expensive easier ways to check health advice that fits different cultures and apps that can help lots of people. When we gather data, gut information, health details and lifestyle facts, we get permission, keep it safe, make sure it is fair and use smart computers properly. Future work should also bring together experts, such as nutritionists, doctors, scientists, people who study health trends, people who work with data, people who make rules and the people who live in the communities. In the end, precision nutrition will work best when we use what we know about each person's body, and also use the ways to help everyone stay healthy. Better research and tools, clear rules and fair ways to use these ideas can help us learn how precision nutrition can help prevent diseases and make everyone healthier (Laitinen et al., 2025).

CONCLUSIONS

New research also shows that these problems might be connected to brain issues through the gut-brain link (Seifishahpar et al., 2025). From the point of view of helping people stay healthy learning about how food and gut bacteria work can help prevent diseases with easy and lasting food choices. Encouraging eating habits and more fibre can make the gut healthier and improve overall nutrition. Not everyone reacts the same to food because of their genes, age, way of life where they live medicines they take and their health. So future plans for food might need to be more personal of one size fits all. At the time treatments like probiotics, prebiotics and special diets need more research to see if they work and are safe. Public health rules should include teaching people about food stopping diseases caused by eating making healthy foods available and cheap and studying the gut bacteria. Doctors, nutritionists, scientists, researchers and leaders can all help turn what we know about the gut into help (Luo et al., 2025). It's important that this new science works with the ways of eating well moving around getting medical care and looking at how society affects health. More study on the chemicals, gut walls immune messages and the gut-brain link can help explain how food affects health. In the end how food and gut bacteria work together gives a way to see how food, health, immunity and brain function all connect. A plan that uses food advice, research on the gut personal plans and fair access to healthy food could help lower the problems from long-term health issues and make people healthier, in the long run (Aslam et al., 2026).

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