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Chapter 5
Gut Microbiota and Its Relationship with Nutritional Health

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Abstract

The intestinal microbiota plays a crucial role in health and in the development of various diseases, therefore, the health of a person is influenced by various factors such as biology, lifestyle and environment. Because of this, microbial colonization plays a crucial role in many of these variables, which, if altered, would have a considerable impact on the health of the host. Therefore, appropriate nutritional intervention can have a significant impact on the optimal state of the intestinal microbiota, since diet directly influences the composition and diversity of bacteria and other microorganisms that inhabit the intestine. Through various mechanisms, nutrition can help balance and improve the health of microbiota.
Keywords:
Physiology; Metabolism; Gut microbiota; Nutrition; Health.

Introduction

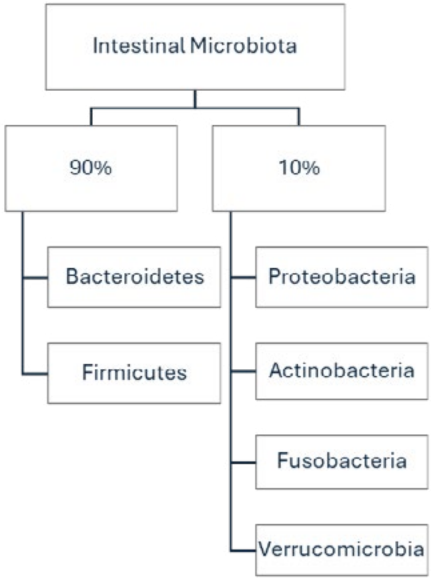
The gut microbiota is a vast community of living microorganisms residing in the digestive tract, which has a direct impact on nutritional health. This is because the gut microbiota performs important functions for health, including vitamin production, food digestion and metabolism, immune system stimulation, as well as preventing pathogen entry into the body and degrading foodborne toxins that could harm the host. Maintaining an optimal state of the gut microbiota may help reduce the risk of developing chronic diseases such as type 2 diabetes mellitus, obesity, inflammatory bowel diseases, and certain types of cancer, as alterations in the gut microbiota have been linked to the onset of these conditions.

In this chapter, we will explore in-depth how gut microbiota influences individual nutritional and general health, the dietary and environmental factors that modify it, and the dietary interventions that can contribute to improving its composition and function. Additionally, we will review the specific mechanisms of the gut microbiota, its interaction with the host, potential applications in disease treatment, and health promotion through diet.

Intestinal Microbiota

The intestinal microbiota is a complex entity that is considered an external organ of the body. It is composed of trillions of microorganisms, including hundreds of different bacterial species. Its composition varies depending on factors such as age and dietary habits (Garza-Velazco et al., 2021). The intestinal microbiota consists of a vast diversity of microorganisms; however, this ecosystem includes approximately 100 trillion microbial cells with around 9.9 million genes in total (Merino et al., 2021). Upon reaching adulthood, the intestinal microbiota is composed as shown in Figure 1. Although each individual has a unique composition of intestinal microbiota, there are patterns that are defined as enterotypes (Álvarez, et al., 2021).

Figure 1. Types of microbiota present in the intestine



Source: Álvarez et al. (2021).

Factors Influencing Microbial Diversity

Diet is directly related to the microbial diversity of the host. From birth, the type of feeding—whether exclusive breastfeeding or formula—affects the composition of the intestinal microbiota. The microbial population in newborns is crucial, as breast milk facilitates the transfer of beneficial microbiota to the infant's intestine (Senchukova, 2023). Microbial diversity (Table 1) at any stage of life is influenced by the consumption of different types of sugars or sweeteners. It has also been shown that sugar and sweetener intake impact the intestinal microbial population, leading to genetic changes. When sugars and sweeteners are incorporated into the diet, intestinal microorganisms may begin modifying their transcriptional profiles, causing metabolic alterations and changes in microbiome composition (Di Rienzi & Britton, 2020).

Table 1. presents some effects of consuming different types of sugar on intestinal bacteria and their physiological impact.

Bacteria	Physiological Alterations	Related Pathologies	Effects of Sugar Consumption
Lactobacillus spp.	SCFA production; anti-inflammatory and anticancer activities	Decreases IBD	Increases its population with lactose and decreases with artificial sweeteners.
Bifidobacterium spp.	SCFA production; improves intestinal mucosal barrier	Reduced abundance in obesity	Increases its population with lactose, fructose, glucose, and decreases with artificial sweeteners.
Bacteroides spp.	Activates CD4 + T lymphocytes	Increased abundance in IBD	Its population decreases with glucose, lactose, and fructose, and increases with artificial sweeteners.
Clostridium spp.	Promotes TH17 cell generation	Some species are pathogenic, causing botulism or Pseudomembranous colitis	Decreases with lactose and artificial sweeteners.
Faecalibacterium prausnitzii	SCFA production; anti-inflammatory effects	Reduced abundance in IBD and obesity	—

Source: Singh et al. (2017).

On the other hand, not only does diet impact microbial diversity, but moderate- and high-intensity exercise also has positive effects on the intestinal microbiota. However, if the intestinal microbiota is not in a healthy state, it can negatively influence physical performance. High-performance athletes exhibit greater microbial diversity, which translates into increased production of short-chain fatty acids (SCFAs), such as butyrate and propionate (Clauss et al., 2021).

Functions, digestion and metabolism of the Gut Microbiota

The gut microbiota plays a fundamental role not only in nutrient digestion and absorption but also in immune system regulation and protection against pathogens that can cause infections and intoxications. Additionally, it is key to the body's overall metabolism. Therefore, maintaining microbiota balance is essential for host well-being, as its disruption can lead to various diseases (Rowland et al., 2017).

The gut microbiota plays a crucial role in host metabolism, possessing enzymes capable of transforming dietary carbohydrates that cannot be fully digested or absorbed in the small intestine. These carbohydrates reach the colon, where microorganisms ferment them to produce short-chain fatty acids (SCFAs), which can be used as an energy source by intestinal epithelial cells or transported through the circulatory system to distant organs, where they play important metabolic roles (Álvarez et al., 2021). Another metabolic process regulated by the gut microbiota is bile acid transformation. These acids act as signaling molecules that regulate both lipid absorption and cholesterol homeostasis (Jaillier-Ramírez et al., 2021).

Immune system modulation

The gut microbiota is acquired rapidly from birth and, despite some variability, tends to remain relatively stable throughout life, being essential for proper human homeostasis. At birth, the newborn has a fully developed but immature immune system. In the first hours of life, intestinal colonization begins, influenced by factors such as gestational age, mode of delivery, neonatal nutrition, and individual genetics (Alarcón et al., 2016). These microorganisms play a crucial role in forming intestinal barriers and producing immune cells such as lymphocytes, as well as in antibody formation. Although a healthy person's microbiome is relatively stable, its dynamics can be affected by lifestyle and dietary choices (Singh et al., 2017). Gut microbiota health directly influences inflammatory responses, with implications for inflammatory bowel diseases, skin conditions such as psoriasis and atopic dermatitis, and chronic metabolic diseases, including obesity, type 2 diabetes, and cardiovascular diseases (Gentile & Weir, 2016). Singh et al. (2017), mention that immune cells located in the intestine, such as dendritic cells and T lymphocytes, directly interact with gut microorganisms. These cells can recognize specific microbial patterns and activate appropriate immune responses or, alternatively, promote immune tolerance to avoid inappropriate responses. In this context, gut microbiota helps maintain a balance between immune tolerance and immune responses to pathogens (Garza-Velasco et al., 2021). Additionally, gut microorganisms produce bioactive signals that educate the immune system to differentiate between beneficial microbes and nutrients versus harmful pathogens or substances that could disrupt homeostasis. Nutrients in the diet are essential not only for human health but also for the well-being and survival of the trillions of microorganisms inhabiting the gut (Garza-Velasco et al., 2021).

Production of vitamins and essential nutrients

The gut microbiota facilitates nutrient extraction from food and plays a role in the production of vitamins such as vitamin K and folic acid. It also contributes to the synthesis of amino acids (Rowland et al., 2017).

Function of intestinal barrier integrity

The gastrointestinal tract mucosa is lined with epithelial cells that create an effective barrier through intercellular junctions, separating the internal environment from the external one and preventing the entry of toxins, microorganisms, and other agents that could cause harm to the body. However, as previously mentioned, epithelial cells also play a fundamental role in the absorption of nutrients and electrolytes. To fulfill this function, the intestinal barrier must be semi-permeable, allowing the selective passage of beneficial substances while blocking the entry of harmful compounds. To achieve this, the intestine has developed a defensive system (intestinal barrier), which is essential for protection against antigens, toxins, and microbial products (Salvo-Romero et al., 2015).

At the same time, the intestinal barrier plays a crucial role in regulating the immune system, helping maintain tolerance toward non-pathogenic components present in the intestine, such as those derived from food and gut microbiota, while activating an immune response against invading pathogens. When this barrier is in good condition, it prevents chronic inflammation and avoids uncontrolled immune responses that could lead to inflammatory bowel diseases, such as Crohn’s disease or ulcerative colitis (Salvo-Romero et al., 2015).

Dietary factors that modulate the gut microbiota

The dietary factors that modulate the gut microbiota include: dietary fiber is an indigestible carbohydrate that is not enzymatically degraded in the small intestine. Instead, it moves to the large intestine, where it is fermented by resident microorganisms. Consequently, dietary fiber serves as a good source of “microbiota-accessible carbohydrates,” which microbes can utilize to provide the host with energy and a carbon source (Pistollato et al., 2016). Through this process, dietary fiber can modify the intestinal environment. This property justifies its additional designation as a prebiotic—non-digestible dietary components that benefit host health by selectively stimulating the growth and/or activity of certain microorganisms. Sources of prebiotics include soy, inulins, unrefined wheat and barley, raw oats, and non-digestible oligosaccharides (Pandey et al., 2015). A diet low in these substances has been shown to reduce total bacterial abundance (Halmos et al., 2015).

Use of probiotics and prebiotics

Probiotics (Table 2) and prebiotics (Table 3) are valuable tools for improving gut microbiota health.

Table 2. Functions and examples of Probiotics.

Functions	Examples
Improve gut microbiota composition	Lactobacillus acidophilus
Increase the production of short-chain fatty acids.	Bifidobacterium bifidum
Improve intestinal barrier function.	Streptococcus thermophilus
Reduce inflammation and oxidative stress.	Saccharomyces boulardii
Enhance immune response.	

Source: own elaboration

Fermented foods containing lactic acid bacteria, such as cultured dairy products and yogurt, serve as a source of ingestible microorganisms that can beneficially regulate gut health and even help treat or prevent inflammatory bowel disease (Shen et al., 2014). Based on these properties, foods enriched with these modulating microorganisms are referred to as probiotics. Several studies have observed an increase in total bacterial load following regular consumption of fermented milk or yogurt (Matsumoto et al., 2010). Notable increases in beneficial intestinal Bifidobacteria and/or Lactobacilli have also been observed with various types of probiotics (Carnicer et al., 2006).

Table 3. Functions and examples of Prebiotics

Functions	**Examples**
1. Increase the population of beneficial bacteria.	Inulin
2. Improve the production of short-chain fatty acids.	Fructooligosaccharides (FOS)
3. Improve intestinal barrier function.	Galactooligosaccharides (GOS)
4. Reduce inflammation and oxidative stress.	-glucans

Source: own elaboration

According to Floch et al. (2006), before using probiotics or prebiotics, it is important to consider the following contraindications and precautions:

- Patients with compromised immune systems
- Patients with chronic diseases, such as diabetes or cardiovascular diseases.
- Patients taking medications that may interact with probiotics or prebiotics
- Patients with allergies or intolerances to certain ingredients.

It is essential to consult a healthcare professional before using probiotics or prebiotics, especially if there are underlying health conditions or if medications are being taken. Increasing fiber intake is an effective strategy for improving gut microbiota health. Below are some benefits and recommendations for increasing fiber consumption (Table 4)

Table 4. Benefits and Recommendations Related to Fiber Intake

<table>
<tr><th>Benefits</th><th>Recommendations</th></tr>
<tr><td>Increases gut microbiota diversity.</td><td>Consume at least 25-30 grams of fiber per day.</td></tr>
<tr><td>Promotes the growth of beneficial bacteria.</td><td rowspan="2">Include a variety of fiber-rich foods in the diet, such as:
- Fruits: apples, bananas, strawberries.
- Vegetables: broccoli, carrots, spinach.
- Whole grains: oats, quinoa, brown rice.
- Legumes: lentils, chickpeas, beans.
- Nuts and seeds: almonds, chia seeds.</td></tr>
<tr><td>Improves the production of short-chain fatty acids.</td></tr>
</table>

Benefits	Recommendations
Helps regulate intestinal transit.	Gradually increase fiber intake to avoid digestive issues.
May reduce the risk of chronic diseases such as obesity, diabetes, and cardiovascular diseases.	Drink enough water to help fiber move through the digestive tract.

It is important to consult a healthcare professional before making significant changes to your diet.

Source: own elaboration

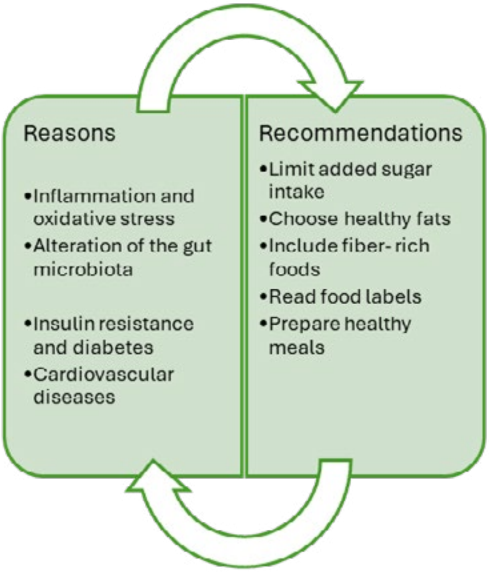
Proteins and fats

According to Singh et al. (2017), an experiment administered different protein sources to participants: animal-based (meat, eggs, and cheese), whey protein, and plant-based protein (such as pea protein). Most studies indicated that protein consumption correlates positively with gut microbiota diversity. However, some results showed that plant-based proteins are associated with lower mortality compared to animal-based proteins. It is important to highlight that diets rich in animal products provide not only proteins but also fats, which could influence microbial composition. In fact, several human studies suggest that a high-fat diet increases total anaerobic microflora and Bacteroides counts.

Reducing the consumption of refined sugars and saturated fats

Reducing the consumption of sugars and saturated fats is essential for improving gut microbiota health (Sonnenburg & Sonnenburg, 2014).

Figure 2. Description of reasons and recommendations for reducing sugar and saturated fat consumption.



Source:

Refined sugars and processed foods

Processed foods are industrially manufactured, often pre-packaged, convenient, energy-dense, and nutrient-poor. Processed foods are widespread in the modern Western diet, and numerous studies support their potential contribution to non-communicable diseases such as obesity and cardiovascular diseases. It is believed that processed foods affect the body in multiple ways, including inducing changes in the gut microbiome (Brichacek et al., 2024). Additionally, long-term dietary habits characterized by high intake of refined sugars or fats have been linked to a pro-inflammatory intestinal environment and the depletion of beneficial bacteria, along with an enrichment of pathogenic and pro-inflammatory microbes (Antonini et al., 2019). These changes can impair butyrate production and induce inflammatory responses, damaging intestinal barrier permeability and causing uncomfortable gastrointestinal symptoms such as bloating or flatulence (Dahl & Stewart, 2015). Other dietary factors that modulate the gut microbiota include carbohydrates, fermented foods, artificial sweeteners, antioxidants, polyphenols, water, hydration levels, vitamins, and minerals (Singh et al., 2017). It is important to highlight that each person has a unique gut microbiota, and responses to dietary factors may vary from one individual to another. A balanced and varied diet rich in fruits, vegetables, whole grains, and fermented foods can help maintain a healthy gut microbiota.

Impact of the microbiota on intestinal health and diseases

The intestinal microbiota and the microorganisms that inhabit it have revealed a significant role in human health, as they are directly related to dietary patterns and the host's lifestyle, being a key factor in the modulation of chronic diseases, affecting the immune system and metabolism (Chávez, 2013).

Obesity is a metabolic pathology characterized by excessive accumulation of body fat. However, the relationship between the intestinal microbiota (IM) and obesity-related issues emerged from a study conducted with germ-free mice and normal mice. This study showed that germ-free mice began to develop increased leptin levels, insulin resistance, and had a higher percentage of adipose tissue compared to normal mice. (Farías et al., 2011). This type of phenotype is transmissible and could be caused by intestinal dysbiosis, where the introduction of high-fat diets promotes the ability to collect energy. An increase in Firmicutes-type bacteria has been associated with disorders such as Metabolic Syndrome (MS) and obesity (Salinas, 2013). According to Khan et al. (2014), "Obesity is currently at the intersection of inflammatory and metabolic disorders, causing an alteration in immune activity that increases the risk of developing diabetes, atherosclerosis, fatty liver disease, and lung inflammation".

Type 2 Diabetes Mellitus

Type 2 Diabetes Mellitus (T2DM) is a public health issue. Individuals suffering from this disease are often characterized by leading a sedentary lifestyle, having a high intake of simple carbohydrates, suffering from obesity, and presenting genetic factors. (Awad et al., 2020). Research on the pathogenesis of T2DM has demonstrated an increase in the proportion of Firmicutes and Bacteroides bacteria in patients with this condition. This microbial imbalance contributes to systemic inflammation, insulin resistance, and the development of diabetes. This is partly due to the fact that the cell membranes of gram-negative bacteria are primarily composed of lipopolysaccharides (LPS), which are potent stimulants of inflammation. (Farías et al., 2011). Additionally, the development of T2DM is linked to metabolites produced by the intestinal microbiota, which can affect the function of pancreatic β-cells and alter glucose and lipid metabolism. One of these metabolites, Trimethylamine-N-oxide (TMAO), impairs glucose tolerance by blocking the hepatic insulin signaling pathway (Wu J. Yang et al., 2023).

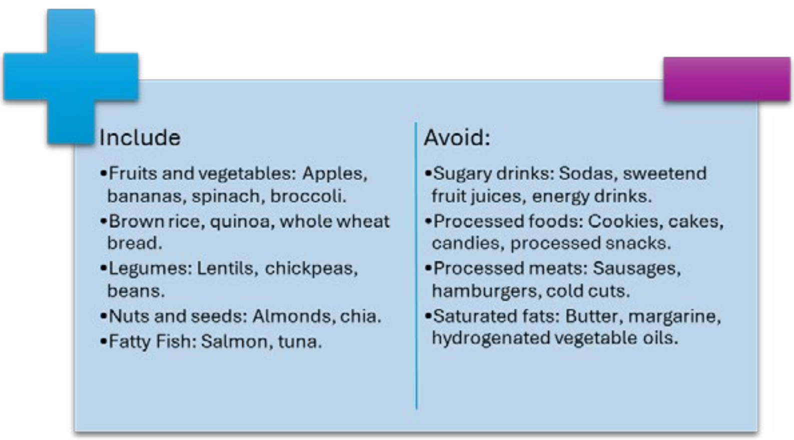
Cardiovascular diseases

Cardiovascular Diseases (CVD) have had a significant impact worldwide, and the primary cause of these pathologies is attributed to dietary habits. A high intake of lipids, saturated fatty acids, and proteins activates metabolic processes that interact with bacteria involved in lipid absorption through the activation of receptors, secretin, and cholecystokinin. (Senchukova, 2023). Excessive consumption of red meat promotes an increase in the metabolite Trimethylamine-N-oxide (TMAO), accelerating the metabolism of choline and phosphatidylcholine, creating a significant risk of atherosclerosis (Singh et al., 2017).

Gastrointestinal and inflammatory disorders

Irritable Bowel Syndrome is associated with a low diversity of bacteria from the genera Bacteroides and Firmicutes, leading to a decrease in the production of butyrate and other short-chain fatty acids (SCFAs), compounds known for their anti-inflammatory functions (Singh et al., 2017). On the other hand, in Inflammatory Bowel Disease, lesions occur in the intestinal tract, and patients present a microbiota significantly different from that of healthy individuals. The main cause of this alteration is dysbiosis, characterized by poor diversification of the intestinal microbiota. In these cases, bacteria such as Clostridium, Bacteroides, and Bifidobacteria predominate (Polanco, 2015).

Figure 3. Displays foods to avoid and include to improve gut microbiota health, increasing fiber intake and healthy fats.



Source:

Conclusion

The gut microbiota is essential for maintaining health. Various alterations in its composition contribute to the development of inflammatory, metabolic, and cardiovascular diseases. It is crucial to maintain microbial homeostasis through a varied and balanced diet that includes dietary fiber and probiotics, while regulating protein, fat, and sugar intake, alongside regular physical activity. Despite extensive research on gut microbiota, it remains an active area of study due to its significant role in human physiology and pathophysiology.

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La microbiota intestinal y su relación con la salud nutricional

Microbiota intestinal e sua relação com a saúde nutricional

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Resumen

La microbiota intestinal desempeña un papel crucial en la salud y en el desarrollo de diversas enfermedades, por lo que la salud de una persona está influida por diversos factores como la biología, el estilo de vida y el entorno. Por ello, la colonización microbiana desempeña un papel crucial en muchas de estas variables que, de alterarse, tendrían un impacto considerable en la salud del huésped. Por lo tanto, una intervención nutricional adecuada puede tener un impacto significativo en el estado óptimo de la microbiota intestinal, ya que la dieta influye directamente en la composición y diversidad de las bacterias y otros microorganismos que habitan en el intestino. A través de diversos mecanismos, la nutrición puede contribuir a equilibrar y mejorar la salud de la microbiota.
Palabras clave:
Fisiología; metabolismo; microbiota; nutrición; salud.

Resumo

A microbiota intestinal desempenha um papel crucial na saúde e no desenvolvimento de diversas doenças, por isso a saúde de uma pessoa é influenciada por diversos fatores, como a biologia, o estilo de vida e o ambiente. Por isso, a colonização microbiana desempenha um papel crucial em muitas dessas variáveis que, se alteradas, teriam um impacto considerável na saúde do hospedeiro. Portanto, uma intervenção nutricional adequada pode ter um impacto significativo no estado óptimo da microbiota intestinal, já que a dieta influencia diretamente a composição e diversidade das bactérias e outros

microrganismos que habitam o intestino. Através de diversos mecanismos, a nutrição pode contribuir para equilibrar e melhorar a saúde da microbiota.
Palavras-chave:
Fisiologia; Metabolismo; Microbiota intestinal; Nutrição; Saúde.