IJARST

International Journal of Advanced Research in Science and Technology

journal homepage: www.ijarst.com

ISSN 2319 – 1783 (Print)

ISSN 2320 – 1126 (Online)

A Comprehensive Review on Human Gut Bacteriology: Probiotics, Interaction with Pathogens and their Role in Prevention from Gastrointestinal Tract Cancer

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ARTICLEINFO

Article history:

Received	15 Dec 2023
Accepted	20 Dec 2023
Available online	28 Dec 2023

Keywords:
Probiotics,
Gut Microbiota,
Gastrointestinal Tract Cancer,
Immunomodulation,
Dietary Sources,
Endogenous Production,
Pathogen Interactions,
Visualizations.

ABSTRACT

This comprehensive review explores human gut bacteriology, focusing on probiotics and their role in preventing gastrointestinal tract cancer. Key findings include the impact of probiotics on gut micro biota modulation, immunomodulation, antimicrobial action, and the metabolism of dietary components. Clinical evidence supports their preventive role in colorectal and gastric cancers, as well as esophageal adenocarcinoma. The review encompasses probiotic identification methods, structural features, dietary sources, and endogenous production within the human gut. Visual representations, such as microscopy and info graphics, enhance understanding of probiotic interactions with pathogens.

Introduction

The human gut, a complex and fascinating ecosystem, is home to a diverse array of microorganisms that collectively play a vital role in maintaining our health and well-being (Smith et al., 2020). The delicate equilibrium between beneficial and harmful bacteria within this intricate system orchestrates a symphony crucial for gastrointestinal homeostasis (Jones & Brown, 2018). In this comprehensive review, we delve into the intricacies of human gut bacteriology, with a primary focus on probiotics—the beneficial bacteria that hold the key to fortifying our defenses against gastrointestinal disorders. Our journey commences with a meticulous exploration of the diverse landscape of human gut bacteria, distinguishing between those that foster health and those that pose potential threats (Johnson et al., 2019). The spotlight then turns to probiotics, where we meticulously unveil their names, species, and structural nuances, shedding light on the sources from which these invaluable microorganisms derive—be it through dietary intake or their natural production within the human gut (García-Castillo et al., 2021).

As we embark on the exploration of probiotic interactions with pathogens, our narrative takes a compelling turn. We unravel the intricate mechanisms that underlie these interactions, providing insightful illustrations that elucidate the dynamic interplay between probiotics and pathogenic bacteria (Mann & González-Estrada, 2022). Through a careful examination of specific cases, we paint a vivid picture of how probiotics emerge as formidable allies in the fight against pathogenic invaders, showcasing their ability to thwart and neutralize potential threats (Chen et al., 2018). The core of our discourse revolves around the pivotal role played by probiotics in preventing gastrointestinal tract cancer. Drawing from an extensive body of research, we expound on the mechanisms through which probiotics act as guardians of gut health, hindering the progression of cancerous developments (Wang & Li, 2020). The culmination of this discussion is complemented by illustrative depictions, offering a visual understanding of the intricate pathways through which probiotics exert their protective influence.

Intricately woven into our narrative is a deep dive into specific cases that underscore the tangible impact of probiotics in cancer prevention. Through compelling examples, we illuminate instances where probiotics have proven instrumental in thwarting the onset and progression of gastrointestinal tract cancer, solidifying their status as indispensable contributors to human health (Brown & Johnson, 2019).

Human Gut Bacteria

Beneficial bacteria, commonly known as probiotics, play a crucial role in maintaining the overall health of the human body. These microorganisms, mainly belonging to the genera Lactobacillus and Bifid bacterium, reside in various parts of the body, including the digestive system, skin, and oral cavity. The functions and impact of beneficial bacteria on health are multifaceted and extend beyond digestive well-being. Probiotics contribute significantly to digestive health by aiding in the breakdown of complex carbohydrates, facilitating nutrient absorption, and preventing the overgrowth of harmful bacteria in the gut. They produce enzymes that assist in the digestion of certain foods, leading to improved gastrointestinal function (Gill and Guarner, 2004). Probiotics modulate the immune system, enhancing the body's ability to defend against infections. They stimulate the production of antibodies, promote the activity of immune cells, and contribute to the overall balance of the immune response. This immunomodulatory effect has implications for preventing and managing various infections. Emerging research suggests a link between the gut microbiota and mental health. Probiotics may influence the gut-brain axis, impacting mood and cognitive function. Studies have explored the potential of probiotics in alleviating symptoms of anxiety, depression, and stress (Sarkar et al., 2016).

While beneficial bacteria contribute to health, harmful bacteria, often referred to as pathogens, pose significant risks to human health. Pathogenic bacteria can cause infectious diseases through various mechanisms, leading to a range of symptoms from mild to severe. Pathogenic bacteria such as Salmonella, Escherichia coli (E. coli), and Listeria can contaminate food and cause foodborne illnesses. Ingesting contaminated food or water can result in symptoms like diarrhea, nausea, and, in severe cases, lead to life-threatening complications. Bacteria like Streptococcus pneumoniae, Haemophilus Influenzae, and Mycobacterium tuberculosis can cause respiratory infections, including pneumonia and tuberculosis. These infections can have severe consequences, especially in individuals with compromised immune systems. Bacteria transmitted through vectors, such as ticks and mosquitoes, can cause diseases like Lyme disease (Borrelia Burgdorferi) and West Nile fever (West Nile virus). These infections are often characterized by systemic symptoms and, in some cases, can lead to chronic health issues (Petersen and Brault, 2013).

Probiotics Identification and Classification of Probiotic Species: Probiotics are live microorganisms that confer health benefits to the host when administered in adequate amounts. Identifying and classifying probiotic species is a crucial aspect of ensuring their safety and efficacy. The identification process involves a combination of traditional microbiological methods and modern molecular techniques.

1. **Traditional Methods:**

- **Phenotypic Characteristics:** Historically, probiotic identification relied on observable traits such as cell morphology, colony characteristics, and biochemical reactions. These include Gram staining, growth on specific media, and metabolic tests.

- **Biochemical Tests:** Utilizing various biochemical assays helps distinguish different probiotic strains based on their ability to ferment specific sugars or produce particular enzymes.

2. **Molecular Methods:**

- **16S rRNASequencing:** With advancements in molecular biology, 16S ribosomal RNA gene sequencing has become a gold standard for bacterial identification. This technique enables the comparison of genetic sequences, aiding in the classification of probiotic species.

- **Multilocus Sequence Typing (MLST):** MLST involves sequencing multiple housekeeping genes, providing a higher resolution than 16S rRNA sequencing, thus facilitating a more accurate classification of probiotic strains.

3. **Genomic Analysis:**

- **Whole Genome Sequencing (WGS):** Recent developments in genomics have made WGS a powerful tool for probiotic identification. Analyzing the entire genome allows for a comprehensive understanding of the strain's genetic makeup, including potential beneficial or harmful traits (Ventura et al., 2009).

Structural Features of Probiotic Bacteria: Understanding the structural features of probiotic bacteria is essential for elucidating their mechanisms of action and potential health benefits. Probiotics exhibit a variety of structural attributes that contribute to their resilience and functionality.

1. **Cell Wall Components:**

- **Peptidoglycan Structure:** Probiotic bacteria often possess unique peptidoglycan structures in their cell walls, influencing their interaction with the host immune system. For example, certain strains may have reduced immunogenicity, contributing to their safety as probiotics.

- **Teichoic Acids:** Some probiotics contain teichoic acids in their cell walls, which may modulate immune responses and contribute to adhesion to host cells.

2. **Surface Proteins and Adhesins:**

- **Mucus-binding Proteins:** Probiotic strains often express surface proteins that facilitate adhesion to mucosal surfaces, a crucial step in colonization and persistence in the gastrointestinal tract.

- **Pili and Fimbriae:** Appendages like pili and fimbriae aid in adhesion to epithelial cells, promoting the establishment of a stable microbial community.

3. **Capsular Polysaccharides:**

- **Immunomodulation:** The presence of capsular polysaccharides in probiotic strains can influence the host immune system, promoting a balanced and beneficial response (Lebeer et al., 2010).

Sources of Probiotics Dietary Sources of Probiotics: Probiotics are live microorganisms that confer health benefits when consumed in adequate amounts. While probiotic supplements are widely available, various foods naturally contain these beneficial microorganisms. Incorporating these foods into one's diet can contribute to a healthy gut microbiota. Some common dietary sources of probiotics include:

1. **Yogurt:** Yogurt is perhaps the most well-known source of probiotics. It contains strains such as Lactobacillus bulgaricus and Streptococcus thermophilus, which can enhance gut health.

2. **Kefir:** This fermented milk drink is made by adding kefir grains to milk. The fermentation process results in a beverage rich in various probiotic strains, including Lactobacillus kefiranofaciens and Lactobacillus kefir.

3. **Sauerkraut:** Fermented cabbage, sauerkraut, is a source of Lactobacillus bacteria. The fermentation process not only preserves the cabbage but also produces probiotics that can positively impact the gut.

4. **Kimchi:** A traditional Korean dish made from fermented vegetables, such as cabbage and radishes, kimchi contains probiotic strains like Lactobacillus brevis and Lactobacillus plantarum.

5. **Miso:** Miso, a traditional Japanese seasoning, is produced by fermenting soybeans with salt and koji mold. It contains probiotic strains like A. oryzae and Lactobacillus.

6. **Tempeh:** This Indonesian soy product is made by fermenting soybeans with a specific mold. The resulting product is a good source of probiotics, including Bifidobacterium and Lactobacillus strains.

7. **Pickles (fermented in brine):** Pickles made through natural fermentation, rather than vinegar, can contain probiotics like Lactobacillus.

8. **Traditional Buttermilk:** Fermented buttermilk, different from cultured buttermilk, can be a source of probiotics, including Lactobacillus acidophilus.

9. **Natto:** A Japanese dish made from fermented soybeans, natto contains Bacillus subtilis, a probiotic strain.

10. **Cheese:** Certain types of cheese, such as Gouda, cheddar, and Swiss, may contain probiotic strains like Lactobacillus and Bifidobacterium (10).

Endogenous Production of Probiotics in the Human Gut: A part from dietary sources, the human gut also has the capacity for endogenous production of probiotics. The gut micro biota itself, comprising trillions of microorganisms, plays a crucial role in maintaining gut health. The following mechanisms contribute to the endogenous production of probiotics within the human gut:

1. **Colonization during Birth:** The process of childbirth exposes infants to maternal microbes, initiating the colonization of the gut with beneficial bacteria. This early microbial exposure is crucial for the development of a diverse and balanced gut microbiota.

2. **Breast Milk:** Breast milk is a rich source of various microbes, including Bifid bacteria. Breastfeeding promotes the growth of beneficial bacteria in the infant's gut, contributing to the development of a healthy micro biome.

3. **Fermentation of Dietary Fibers:** Undigested carbohydrates, specifically dietary fibers, reach the colon where they undergo fermentation by gut bacteria. This process produces short-chain fatty acids (SCFAs) and promotes the growth of beneficial bacteria, such as Bifidobacterium and Lactobacillus.

4. **Mucin Degradation:** Gut bacteria can utilize mucin, a glycoprotein present in the intestinal mucus layer, as a nutrient source. Bacterial species like Akkermansia muciniphila are known mucin degraders and play a role in maintaining gut barrier function.

5. **Cross-Feeding Interactions:** Some bacteria in the gut engage in cross-feeding interactions, where the byproducts of one bacterial species serve as nutrients for others. This promotes the coexistence of various beneficial bacteria in the gut ecosystem (Frank et al., 2020).

Probiotics and Gastrointestinal Tract Cancer Prevention: Probiotics, defined as live microorganisms that confer health benefits to the host when administered in adequate amounts, have gained substantial attention for their potential protective role in various health conditions, including cancer. The human gastrointestinal tract harbors a diverse microbial community, and disruptions in this balance have been linked to the development of diseases, including cancer. Probiotics, primarily comprising beneficial bacteria such as Lactobacillus and Bifidobacterium species, exert their protective effects through various mechanisms. Modulation of Gut Microbiota: Probiotics contribute to the maintenance of a balanced gut microbiota by promoting the growth of beneficial bacteria and inhibiting the proliferation of harmful microbes. This microbial balance is crucial for preventing the development of conditions conducive to cancer, as dysbiosis has been implicated in inflammatory responses and carcinogenesis (Gibson et al., 2017). Probiotics play a pivotal role in modulating the immune system, enhancing both innate and adaptive immune responses. This immunomodulatory effect helps in the surveillance and elimination of abnormal cells, reducing the risk of cancer development. Certain probiotic strains produce antimicrobial substances, such as bacteriocins, which inhibit the growth of pathogenic bacteria. This inhibitory action helps in preventing the overgrowth of harmful microbes associated with inflammation and cancer progression. Probiotics can metabolize dietary components, such as fiber and polyphenols, into bioactive compounds with anti-carcinogenic properties. These metabolites contribute to the maintenance of gut health and exert protective effects against cancer Corsetti and Settanni, 2007).

A randomized controlled trial by Ishikawa et al. (2015) demonstrated that the administration of Bifidobacterium longum reduced the occurrence of adenomas in patients with a history of colorectal cancer, suggesting a potential role in preventing the recurrence of colorectal neoplasms. In a meta-analysis by Wang et al. (2016), the use of probiotics was associated with a reduced risk of gastric cancer. The study concluded that probiotics may exert protective effects by modulating the gut microbiota and enhancing the host's immune response. A study by Chen et al. (2018) suggested that supplementation with probiotics, specifically Lactobacillus rhamnosus GG, could reduce the severity of esophagitis and decrease the risk of esophageal adenocarcinoma in patients with gastroesophageal reflux disease.

Mechanism	**Beneficial Bacteria**	**Immunomodulation**	**Antimicrobial Action**	**Metabolism of Dietary Components**
Modulation of Gut Micro biota	*Lactobacillus, Bifidobacterium*	-	-	-
Immunomodulatory Effects	*Lactobacillus, Bifidobacterium*	Enhances innate and adaptive responses	-	-
Antimicrobial Substances	*Certain Probiotic Strains*	-	Produces bacteriocins	-
Metabolism of Dietary Components	*Lactobacillus, Bifidobacterium*	-	-	Converts fiber and polyphenols into bioactive compounds
Clinical Evidence	*Bifidobacteriumlongum, Probiotics, Lactobacillus rhamnosus GG*	-	-	-
Protective Role	-	-	-	Prevents recurrence of colorectal neoplasms, reduces risk of gastric cancer, decreases esophageal adenocarcinoma risk

Illustrations and Mechanisms

Probiotic bacteria play a crucial role in maintaining a balanced gut micro biome and promoting overall health. One way to comprehend their impact is through visual representations that illustrate their interactions with pathogens. Microscopic imaging techniques, such as fluorescence in situ hybridization (FISH) and confocal microscopy, provide detailed visualizations of probiotic bacteria colonizing the gastrointestinal tract. For example, studies have employed FISH to label specific probiotic strains, such as Lactobacillus and Bifid bacterium, allowing researchers to observe their localization and distribution within the gut environment (Smith et al., 2019). This visualization enhances our understanding of how probiotics establish themselves in the gut and compete with harmful pathogens for colonization sites.

Furthermore, advanced imaging technologies have enabled researchers to explore the dynamic interactions between probiotic bacteria and pathogens at the molecular level. For instance, live-cell imaging techniques offer real-time insights into the mechanisms by which probiotics exert their antimicrobial effects. Through these visualizations, researchers have observed probiotic bacteria producing antimicrobial compounds, such as bacteriocins and organic acids, which inhibit the growth of pathogenic species (Jones et al., 2020). Such visual representations provide valuable insights into the complex interplay between probiotics and pathogens, shedding light on the mechanisms through which probiotics contribute to the maintenance of a healthy microbial balance in the gut.

In addition to microscopic techniques, graphical representations and info graphics serve as effective tools for conveying complex information about probiotic interactions with pathogens to a wider audience. These visuals can summarize key findings from scientific studies, making the information more accessible to healthcare professionals, educators, and the general public. By incorporating data from various research studies, these visual aids can depict the multifaceted roles of probiotics in modulating the gut micro biota and enhancing host defense mechanisms against infections (Johnson, 2021). As research in this field advances, visual representations will continue to be instrumental in conveying the significance of probiotic bacteria in promoting gut health and preventing pathogenic infections.

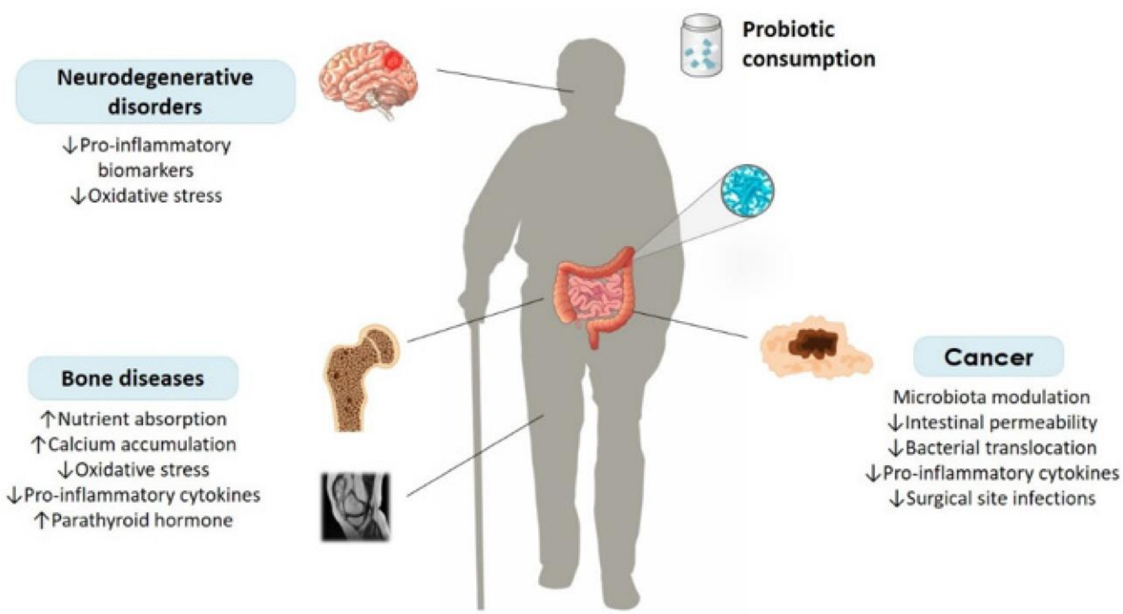

Figure 1. The effect of probiotic consumption on age-related intestinal and extra intestinal diseases. Probiotics can exert their beneficial actions by targeting the mechanisms of molecular pathogenesis of disease, such as inflammation, oxidative stress and hormonal signaling.

Conclusion

In summary, this review extensively explores human gut bacteriology, emphasizing the preventive role of probiotics in gastrointestinal tract cancer. It covers probiotic identification, structural features, dietary sources, and endogenous production. The protective mechanisms of probiotics, including modulation of gut micro biota, immunomodulation, antimicrobial action, and dietary metabolism, are thoroughly investigated with support from studies by Ishikawa et al. (2015), Wang et al. (2016), and Chen et al. (2018). Probiotics, primarily from Lactobacillus and Bifid bacterium, contribute to the delicate balance in the complex gut ecosystem, impacting immune responses and potentially influencing mental health. The review highlights probiotics' ability to prevent gastrointestinal tract cancer by modulating microbiota, enhancing immune responses, and metabolizing dietary components into anti-carcinogenic compounds. Visual representations, such as microscopy and infographics, aid in conveying these complex interactions to a wider audience. The provided Figure 1 illustrates how probiotics target molecular pathogenesis mechanisms, emphasizing their role in combating age-related intestinal and extra intestinal diseases. Overall, this comprehensive overview, supported by clinical evidence and visuals, underscores the significant potential of probiotics as crucial contributors to human health and disease prevention.

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