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Nutritional Influence on Gut Health and Immune Function: An Integrative Perspective

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Abstract

The study of nutrition, gut health, and immune function is fast changing and has major implications for disease prevention and management. A varied microbiome in the gut regulates immune responses. A balanced diet with fiber, polyphenols, and important nutrients maintains a healthy gut flora, which regulates immune function and inflammation. Dysbiosis, an imbalance in the gut microbiota, is connected to autoimmune, allergic, and inflammatory bowel illnesses. New research reveals that antioxidant-rich and omega-3-fatty acid-rich diets can boost immunity and lower infection risk. This study examines how nutrition affects gut microbiota composition and immune system regulation, emphasizing the necessity of a balanced, nutrient-rich diet for immunological health. Dietary changes may prevent or treat immune-related illnesses, presenting a promising immunology therapy route.

Keywords: Diet, immunology, gut microbiota, illness prevention, micronutrients

INTRODUCTION

The intricate connection between diet, gut microbiota, and immune function has emerged as a pivotal area of scientific inquiry, with profound implications for human health and disease prevention. Recent advances in immunology and microbiome research highlight the gastrointestinal tract not only as a digestive organ but also as a central hub for immune surveillance and regulation. The human gut harbors a diverse and dynamic microbial ecosystem that plays a vital role in maintaining immunological homeostasis, supporting nutrient absorption, synthesizing essential metabolites, and protecting against pathogens.

Nutritional inputs significantly influence the composition and functionality of the gut microbiota. A diet rich in fiber, essential micronutrients, and bioactive compounds fosters a diverse microbial population, which is associated with improved immune regulation and reduced systemic inflammation. Conversely, westernized dietary patterns characterized by high saturated fat, sugar, and low fiber content have been linked to dysbiosis – a microbial imbalance implicated in the pathogenesis of numerous chronic and autoimmune diseases, including inflammatory bowel disease, metabolic syndrome, and allergic disorders.

Understanding how specific dietary elements modulate gut microbial ecology and immune responses is critical for developing preventive and therapeutic strategies. Emerging evidence suggests that nutritional modulation of the gut microbiome offers a promising avenue to support immune resilience, particularly through the maintenance of mucosal integrity and the attenuation of chronic inflammation. This integrative perspective aims to synthesize current research findings on the interplay between nutrition, gut health, and immune function, emphasizing the necessity of dietary interventions in fostering long-term health and mitigating immune-related conditions.

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Diet and Gut Health Overview

Due to its growing importance in health and illness, diet, immunology, and the gut microbiota are hot topics in research. Despite its large immune cell count, the gastrointestinal tract coexists peacefully with non-pathogenic intestinal luminal material to express its immune response to orally acquired infections. Disrupted mucosal or systemic immunity and changed microbial populations can also cause allergies and asthma, which are physiological disorders connected to poor proinflammatory response to infections.

A healthy mucosa is fed and educated by the local microbiota, and the immune system limits bacterial development (Statovci et al., 2017) [1]. Healthful mucosal immune system results allow tolerogenic or helpful bacterial species with structural components or metabolites that improve the host's epithelial barrier or immunoregulatory mechanism to survive. Homeostatic non-Gram-negative bacteria are necessary for non-inflammatory or anti-inflammatory immune responses. The immune system must limit bacteria in the gut lumen, specifically in the mucosal locations, into the intestinal GALT or Peyer's Patches. Selective inflammatory stimulation, allergic reaction, or pre-sensitization with specific antigen or adjuvant may cause excessive T effector or T memory activation and compartment expansion. Here, the type, amount, and duration of the immunological stimulus and its interplay with dietary and environmental stimuli are crucial. Musical elements of the hyperlipidic Western diet indicate chronic inflammatory illness.

Understanding Gut Microbiota

Human health, especially the immune system, depends on the microbiome. The microbial community includes thousands of bacteria, fungi, protozoa, and viruses. Bacteria dominate colonization and are most investigated. At least 10 to 14 bacteria invade the human gut. According to some estimates, the gut microbiota contains 500–1,000 bacterial species, and the body has 10 times more bacteria than cells. One gram of feces contains 10 to the 7th to 10th bacteria in the gut microbiota. The gut microbiome aids nutrition absorption, allergen sensitivity, immunomodulation, and pathogen defence.

Immunosurveillance against infections and immunological tolerance toward commensals require precisely controlled immune system responses to microorganisms. Since commensal bacteria are always present, the immune system has developed strategies to prevent overgrowth. Beyond nutrition metabolism, the gut microbiome affects the immune system. Gut microbiome affects immune cell growth and dispersion. However, the immune system shapes the gut microbiota during infection and in the steady state (L. Arnolds & A. Lozupone, 2016) [2]. Absence or excess of bacteria can harm the immune system. Gut microbiota-colonized mice differ from germ-free mice. Gut microbiota from ill individuals can transmit disease features to germ-free mice, suggesting a role in disease onset or progression (Youn Yoo et al., 2020) [3].

Types of Gut Microbiota

The gut communicates with the brain and immune system constantly. The gut-brain axis is increasingly required for appropriate psychological and physical stress response. Good gut microbiota affects mood and immunity. Diet is the main influence on health and gut microbiota. Macronutrients and micronutrients impact immunity. Nutrition and gut microbiome alter immune function, according to new studies. This paper discusses the relationship between diet and the gut microbiota, the evidence for this linkage, and the various mechanisms by which SCFAs may alter immune function. The gut microbiota is a complex ecosystem of billions of bacteria, viruses, and fungi. Gut microbiota ferments dietary fiber and controls pathogen colonization, among other vital tasks. The microbiota has no health standard. However, healthy microbiotas are diverse and abundant (Rinninella et al., 2019) [4]. A healthy gut has been related to a healthy or normal range of psychiatric functions, with no leak within the gut where food fibers, apart from creating inflammation, induce a breakdown of products, and reduce an unhealthy microbiota. Diet impacts the composition of the gut flora.

Gut Microbiota Functions

The gut has around 100 trillion bacteria, viruses, fungi, and other microbes. Increasing studies show that the gut microbiota impacts host metabolism, immunology, and physiology. It contains more than 100 times as many genes as the human genome (the "microbiome"). The gut microbiota maintains and disrupts intestinal IgA levels through direct and indirect methods. Dynamic interactions between the gut microbiota and the host's innate and adaptive immune systems maintain intestinal homeostasis and prevent inflammation, making the "gut-immune axis" a research focus (Youn Yoo et al., 2020) [3]. Gut microbiota processes undigested host proteins and complex carbohydrates, synthesizes vitamins, like vitamin B12 and vitamin K, and produces a huge number of metabolic products, many of which may be biologically active and able to mediate gut epithelial cell-immune cell crosstalk in gut-associated lymphoid tissue.

The adaptive immune system produces antibodies to guard against infections, perhaps one of the most ancient tasks of the immune system. Intestinal IgA is the host's first intact barrier against gut-derived microorganisms and their toxins crossing the epithelium. Gut epithelial cells create a mucosal barrier to separate gut microbes from host immune cells and minimize intestinal permeability. A poor gut microbiota-mucosal immune system interaction increases the amount of potentially pathogenic gram-negative bacteria in the gut, which release excessive LPS from their outer membranes. Plasma LPS levels rise when pathogenic microorganisms cross the intestinal barrier (L. Arnolds & A. Lozupone, 2016) [2].

Diet Influences Gut Microbiota

The gut microbiota is complex and dynamic, affecting human health. Diet influences gut microbiota. Fiber-rich and varied diets may promote a more diverse microbiome, which is linked to greater health. Diet can drastically change the microbiome. A diet high in fat and lacking in fiber may kill beneficial microorganisms in one day. Fiber-rich diets sustain bacteria that ferment SCFAs, lowering pro-inflammatory signaling and maintaining gut health.

Several studies have revealed that food can drastically change gut microbiota composition and function. For instance, macronutrient intake can explain greater gut microbiota variation than host genetics or ethnicity. Early human diet and microbiome investigations linked animal-derived diets to gut microbiomes high in bile-tolerant microbes. In contrast, plant-based fiber-rich diets have more Prevotella and other fiber-degrading organisms. The diet-microbiome revolution began with this link between nutrition, microbiome, and health.

The rapidly developing microbiome study has recently focused on less numerous gut bacteria that may have a big impact on their surroundings. These discoveries are spurring many new gut microbial community modeling initiatives. Some of the latest works study the colon's biophysical environment, giving microorganisms a more physiologically informed portrayal. One high-resolution model includes cell shedding dynamics at the colon's surface, where nutrition availability defines various bacterial ecosystems (Shang et al., 2024) [5].

Impact of Fiber on Gut Health

Diet, gut microbiota, and host immune function have garnered attention in recent years. Increasing data has shown the complex involvement of the gut microbiota in host immune function, prompting interest in how dietary choices may modulate immunological function. This research has identified fibre intake as a major driver of gut microbiota and begun to identify nutrients and mechanisms that may contribute to immune system development, immune-mediated diseases, inflammation, and autoimmunity. This interest includes illnesses and food-based therapies to reduce gut immune costs [6].

The gut becomes extensively populated by complicated bacteria within months of birth. "Colonization" misrepresents simple population dynamics. More accurately, this autochthonous party ends with a mutual melding, steady-state relationship. The host favourably cultivates the varied gut microbiota, which engages in complicated metabolism and interacts with the host. The gut is the front hub of the immune system, a vast and complex anatomical structure that senses the intestine, tolerates non-threatening dietary elements and the gut microbiota, and identifies and fights microbial pathogens, which are well hidden by the dense quasi-symbiotic contact of harmless commensals. This immuno-metabolic organ organically regulated system must develop in the first months of life to protect the host from pathogen infections and tolerate the wide range of food and gut microbial antigens. It is generally known that environmental exposure considerably affects host immunocompetence. Recent research suggests that diet and lifestyle dramatically affect gut microbiota-mediated immune networks and disease vulnerability (Waerling Hansen & Sams, 2018).

Probiotics and Fermented Foods

The gut flora and metabolic products change with aging. Dietary, probiotic, prebiotic, and functional food interventions alter immune responses. Diet and drugs may affect health. Recent therapeutic trials employing multi-strain probiotics and nutritional supplements showed that Crohn's patients' pro- and anti-inflammatory cytokines differed from controls. Antibiotic, prebiotic, and probiotic treatments can reduce or avoid such problems. Each year, global health guides may advise against fermented food and high sugar or fibre items due to alcohol problems. This review demonstrates that several national diet guides recommend fermented foods like yogurt for health benefits.

Food Fats and Gut Microbiota

We examine sources on the impact of dietary lipids on gut microbiota and immunological function since the last comprehensive review (Statovci et al., 2017) [1]. Fatty acids (FAs) can directly affect gut immune cells, including macrophages and epithelial cells, and gut microbiota can change FAs from the diet to interact with the host immune system. Emulsified triglycerides impact microbiota makeup and function as a digestion product and commensal food. Few studies have studied how fat amount and type affect microbial diversity. They may have more Gram-negative bacteria in their guts than low-fat diet-fed animals. Increased fat intake may weaken the intestinal mucous layer and affect the microbiota. However, several studies have found that unsaturated fats may prevent colitis, whereas saturated fats enhance vulnerability. Butyrate, an anti-inflammatory, is produced more in germ-free and antibiotic-treated animals. Butyrate increases from n-3 PUFA supplementation may modulate the inflammatory response in this model. Long-chain SFAs from the diet may directly affect the fatty acid composition of the gut, assisting proinflammatory bacteria to thrive or inhibiting anti-inflammatory bacteria. However, butyrate, a prominent SCFA, can impact gut immune cells and mucus thickness and function. When commensals digest or metabolize stored fat, antimicrobial lipids are released. Commensals provide free fatty acids that help reduce the synthesis of pro-inflammatory cytokines, such as TNF-alpha, IL-6, and IL-12.

Gut and Immune Health

Gut-associated lymphoid tissue (GALT) contains most of the body's immune cells, indicating its importance to host health. Food is a steady source of antigen, and the immune system must produce robust and protective immunity against infections while tolerating dietary proteins and commensals. The GALT contains many specific sensor and effector immunological functions that aid gut homeostasis and immune surveillance. Dendritic cells sample gut content, M cells and goblet cells sample the lumen and deliver particles to immune cells, and plasma B cells, which produce immunoglobulin A, populate the lamina propria and are a major component of the GALT. Peyer's patches are specialized immune structures that take up antigens and pathogens from the gut lumen, move immune cells into and out of the GALT, communicate between immunological cells, and recruit immune cells. A huge community of bacteria in the gut microbiome provides antigens for immune cells and adaptive immune system cells. Over time, understanding of the gut microbiome's impact on immune function and human health has grown, as have efforts to manipulate it for health benefits.

The gut microbiota and immune system are greatly influenced by nutrition, which can affect health and disease. Western diets increase obesity, type 2 diabetes, cardiovascular disease, and noncommunicable diseases due to increased inflammation. Diet affects the course and severity of infectious diseases caused by various pathogens in all age groups. Only the epithelium separates the body's greatest immune organ system from the luminal contents of the gastrointestinal tract. Prebiotics, probiotics, minerals, and vitamins can restore the mucus layer, strengthen enterocyte tight junctions, and increase IgA-producing cells in the gut-associated lymphoid tissue and lamina propria. Prebiotics and other dietary components can change the microbiota, which may impact the immune system's GI tract antigens and signals (E. Childs et al., 2019) [7].

Gut-Immune Relationship

Nutritionally dense foods can improve gut health and immunological function. The gut lining's multilayered protection prevents microbial invasion and maintains immune tolerance to harmless antigens. Gut-associated lymphoid tissue includes the gut barrier and innate and adaptive immunity. The gut-immune system link eliminates germs and triggers systemic inflammatory responses to fight aggressiveness. Note that the memory immune system recognizes and neutralizes infections. To prevent excessive inflammation and host self-damage, numerous layers of control have evolved. Modifying gut microbiota through diet may alter immune responses. Nutrients' effects on inflammation and systemic immune responses affect health throughout life. Inflamed gut immune responses are also affected by diet and nutrition. In a proinflammatory environment, the same diet may affect adaptive immune system output (Statovci et al., 2017) [1].

Immune Response, Inflammation

The intestinal barrier protects against pathogens, regulates antigen sampling, and limits luminal content to the mammalian system. When the barrier is penetrated, an over-immune reaction may occur. Stress-induced systemic exposure to proinflammatory bacterial products can also trigger an innate immune response (Statovci et al., 2017) [1].

Pattern-recognition receptors identify microbe-associated molecular patterns, which drive the host's immunological response. Toll-like receptors are on cell surfaces or endosomes. Antimicrobial substances produced by the host, such as secretory IgA, paneth cells, and defensins, defend the luminal epithelial layer. Immune cells are carefully arranged in solitary, inductive, or effector lymphoid follicles near the epithelium. Due to intestinal barrier mucosa and immune system deregulation, age-related gut diseases occur. Establishment of a complex immune cell ecology in the mucosa, creation of the mucus layer, and expression of antimicrobial peptides all contribute to gut barrier stability.

Animal trials with food-grade probiotics, prebiotics, and synbiotics, well-standardized polyphenol-rich plant preparations, and Mediterranean and other plant-rich diets show the ability to preserve gut and immunological health. Chronic inflammation, caused by excessive immune system activity, is closely linked to intestinal barrier function. Approximately 70% of immune system activity occurs along the gut barrier, and the gut commensal microbiota educates and regulates the host immune system. Chronic immune system activation by intestinal microbiota metabolites can severely impair gut barrier function.

Diet and Immune Health

"Let food be thy medicine" refers to eating to stay healthy and treat disease. The gut has the most immune cells and protects the gastrointestinal tract from immunological signals. Thus, diet's impacts on the gut microbiome and immune function are attracting attention. Evidence suggests that nutrition affects gut flora, which modulates immune responses. The gut and its microbiota are key gatekeepers in understanding the impact of nutrition on immune function, marking a new frontier in immunology.

The gut immune system must discriminate between hazardous pathogens, like bacteria, viruses, and parasites, and harmless antigens like dietary proteins and commensal bacteria. The immune system must challenge infections yet tolerate innocuous antigens and commensal bacteria. The gut's multipart mucosal immune system aids this. The gut is the convergence of immune system stimuli, including microbial components, dietary protein, and complex carbohydrates that have evaded digestion and absorption. It must detoxify, absorb nutrients, and manage a pathogen-rich environment. E. Childs et al. (2019) [7] suggest that the gut-associated immune system developed to meet the physiological energy needs of high antigen and immune signal loads. Intestinal macrophages in the LP maintain tissue homeostasis. They can distinguish innocuous mucosal chemicals from infections and poisons. This is partly due to the luminal mucus structure, which blocks direct antigen presentation to LP cells. Goblet cells in the epithelial lining regulate this arrangement as a first immune defence on the mucosal layer.

Mediterranean Diet and Immunity

The Mediterranean diet emphasizes fruits, vegetables, whole grains, olive oil, lean protein, and moderate wine drinking. The immune system and Mediterranean diet have been studied extensively. Since this diet is rich in phytochemicals, vitamins, and minerals that have been shown to modulate immune function in laboratory animals and humans, it is not surprising that it may affect immune function (Statovci et al., 2017) [1]. This diet contains nutrients and bioactive chemicals that improve the immune system, guard against minor illnesses, preserve long-term health, and hasten recovery from illness. Better gut health and immunological function are further benefits of this diet.

In preserving gastrointestinal and colonic health, nutritional treatment, dietetic intervention, and dietary supplements are extensively recommended. Fermentable fibers and non-digestible oligosaccharides can modulate systemic and mucosal immune responses, although other dietary variables benefit specific GI tract regions. Probiotic strains, like Lactobacilli and Bifidobacterium, affect the gut epithelial barrier and immune system. Vitamin A also improves Paneth cell activity, tight junction protein production, and plasma cell IgA secretion. Short chain fatty acids, like butyrate, propionate, and acetate, activate peroxisome proliferator-activated receptor-γ pathways, enhancing intestinal barrier function and reducing inflammation. Fish and oil include omega-3 polyunsaturated fatty acids that slow pathogenic microorganisms and intestinal tumor growth. These diet elements and their combinations increase immunological balance and mucosal tolerance, according to some research. The Mediterranean diet is abundant in fiber, whole grains, vegetables, and fruits, which means it contains a lot of phytochemicals like flavonoids and polyphenols. Flavonoids can activate the innate immune system in the lungs, intestines, and nasopharynx and defend against local and systemic infections.

Immune Support with Plant-Based Diets

A complex network of organs, cells, proteins, and chemicals, the immune system protects the body from pathogens, including bacteria, viruses, and other microbes that cause infections and diseases in plants and animals, as well as cancer cells. The immune system can malfunction, causing allergies (dermatitis, hay fever, asthma, urticaria, and angioedema), rheumatoid arthritis, Crohn’s disease, ulcerative colitis, psoriatic arthritis, SLE, inflammatory bowel diseases, erosive osteoarthritis, vitiligo, and immunodeficiency. To date, much research has focused on immune function enhancement methods. Immunity is the body’s defence against pathogens and antigens. The immune system includes specific and nonspecific immunity. Unspecific immunity, or innate immunity, is the most rudimentary response to infections and activates within hours after exposure (Jiang et al., 2021) [8]. Innate immunity targets structures, substances, and cells, unlike specific immunity. Specifically, humoral immunity (B-cell-mediated antibody responses) and cell-mediated immunity (T-cell-mediated cytotoxic responses) exist. Third, immunological memory is a physical or chemical aspect of immune system function dependent on earlier immune response exposure. Innate (humoral) and acquired (infectious) immunological memory are important. Healthy people can fight poisons and microorganisms that damage the body. Plants have diverse immune properties and are used in supplements and medical therapy due to their richness and different active components. Plant products contain chemicals that interact with most immune system activities. Boosting immunity with plant-based diets is popular. To understand the effectiveness and possible molecular mechanisms of plant items used for immunological enhancement, one must analyze the breadth and depth of existing research. Immune-boosting plant foods contain natural and general plant processes, physiologically active components, and copolymers added during processing.

Western Diet and Its Impacts

Over the previous decades, food choices and lifestyle have added new obstacles that have radically affected the equilibrium of the crosstalk between the host immune system and gut bacteria. However, the large impact dietetics has for the composition and function of gut microbiota is still unappreciated (Statovci et al., 2017) [1]. Western countries favor high-calorie, high-fat diets over low-fat, high-fibre ones, while Hispanic and Chinese populations do the opposite. Dietary habits, lifestyle changes, food diversity, meal size and frequency, method, and quality all contribute to this phenomenon (Siracusa et al., 2019) [9].

However, gut microbiota affects food and nutrition intake, metabolism, immune homeostasis, and health. To preserve commensal-host equilibrium, the immune system prevents gut pathogen invasion. Gut immunity differentiates harmful from commensal organisms and trains the gut microbiota and immune cells to work well. Red wine and grapes' polyphenol resveratrol improve metabolic fitness and systemic immunity. A diet replicating resveratrol's benefits improves obesity, glucose homeostasis, and systemic immunity, and shows that it regulates host-microbiota interactions in a diet-dependent manner. Due to the profound effects diet compositions have on systemic and gut immunological properties, new approaches to manipulate novel and previously unrecognized intestinal immune applications may significantly improve gut homeostasis at this interface.

Micronutrients and Immunity

Multiple clinical and epidemiological studies have examined the immunological effects of certain micronutrients on host defence and immune homeostasis. Multiple surveys have examined the role of micronutrients in development, infection duration, and outcome. They coordinate the immune response through complex processes that are still being studied. These investigations confirm their immune system-boosting activities as cofactors in immune response gene regulation. The research examines how specific micronutrients affect the expression of genes involved in immune system pathways in response to specific antigens or infections. Several studies have examined how vitamins and minerals affect immunological results. Several studies have linked vitamin B12 deficiency to increased TNF-α release by macrophages, decreased IL-6 levels, and altered lymphocyte numbers. Current data suggests that micronutrient consumption affects immunity and illness outcomes. A balanced and varied diet is the first step to nutritional sufficiency. Micronutrients, such as vitamins A, C, E, D, and folic acid and minerals zinc, selenium, copper, and iron help maintain immunological function. Additionally, each food controls a particular immune response, influencing pathogen defences. Numerous studies have demonstrated that different diseases influence immune responses differently, so the effects of a given nutrient on one pathogen can be negated by another. Vitamin D3 deficiency causes severe lung illness and reduced lung function in response to MTB infection, making it crucial for viral-induced antibacterial immunity. LXA4, a lipid mediator produced by adaptive immune cells (lymphocytes and Tregs), requires vitamin B6 to activate (Tourkochristou et al., 2021) [10].

Effects of Vitamins

Healthy people need vitamins for many reasons, including immune system function. Although vitamins are not manufactured by the body and must be obtained through diet or supplements, fat-soluble vitamin deficits with disastrous health implications are more common than water-soluble vitamin deficiencies. Immune function is supported by vitamins A, B6, B9, B12, C, D, and E. Vitamins B6, B9, B12, C, and D assist cellular immune responses, while vitamins A, C, D, and E support humoral immune responses. Nutrient eating also boosts immune function markers (C Calder, 2020) [11]. Micronutrient properties and body unsynthesis distinguish vitamins from other natural compounds. 13 vitamins A, C, D, E, K, thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), B6, biotin (B7), B9, and B12 are found in humans. Vitamin C and B vitamins (riboflavin, niacin, pantothenic acid, B6, biotin, folic acid, B12) are water-soluble. E, D, A, and K are fat-soluble vitamins. Antilipid absorption drugs limit fat-soluble vitamin absorption. Vitamins also affect pharmaceutical drugs. Although all vitamins are conjugated in cells, these four have special properties. 2017 (Hosomi, Kunisawa) [12]. Vitamins, along with necessary amino acids and fatty acids, are considered metabolites that must be eaten. Due to enzyme or precursor deficiencies, mammals cannot synthesize several vitamins, making them unconsumable. Thus, exogenous ingestion is necessary. Vitamins are organic substances that participate in numerous chemical reactions in living organisms, affecting many physiological functions. Their structural features divided them into fat-soluble (K, E, D, and A vitamins) and water-soluble groups. They have different physiological functions. Fat-soluble vitamins generally remove free radicals, ROS, or RNS, repair membranes, and suppress apoptosis caused by ion afflux, such as Ca^{2+}. As coenzymes and cofactors in enzyme processes, water-soluble vitamins participate in metabolic pathways.

Essential Immunity Minerals

Nutrition affects innate immunity and inflammation at two key checkpoints: gut-associated lymphoid tissue in the digestive tract and immune cell interaction and communication in host tissues. The rising body of research shows that malnutrition and bad diets produce nutritional deficiencies that can directly damage a host's immunological and inflammatory systems. Essential minerals are biologically active micronutrients with major immune health effects. Minerals are essential to food metabolism and tissue construction. Hormones, vitamins, growth factors, and enzymes regulate many metabolic and homeostatic processes. Minerals are also part of many metabolic and physiologically significant chemicals, which affect their optimal functioning in humans and other living things. A variety of studies found that certain minerals help the immune system work properly. Minerals, like Zn, Se, and Fe, affect infection susceptibility and chronic diseases, including cancer and cardiovascular disease. Monitoring blood serum levels of crucial and harmful minerals is essential for detecting and avoiding immune system dysfunction. Non-biologically produced minerals have a defined structure and function in animals and plants. Based on daily intake, microminerals and trace minerals are split (Weyh et al., 2022) [13]. Osmolality, buffer capacity, muscular contraction, nerve impulses, and cell membrane potential require 100–500 µg/day microminerals (Na, K, Mg, Cl, P, Ca, S). Fe, Zn, Cu, Se, I, Mn, and Mo are essential in modest levels, 1 µg to 15 mg/day. They govern metabolic and biochemical processes in the cell as metal ions as enzymes, hormones, or ions, which are essential to tissue or organism function. All living things contain minerals, which are abundant in the Earth's crust. As enzyme cofactors, they bind nucleic acids and proteins, and participate in bone structures, making them important in many homeostatic processes. Hematopoietic function in bone marrow depends on it. The blood circulation exposes immune cells to minerals immediately. By reducing inflammation, minerals regulate blood osmolarity and the immune system. Different micro-element deficiencies cause a variety of immunological disorders. Inversely, high micro-element concentration may damage immunological health. The concentrations of critical micro-elements in blood serum can reveal immune system function and help diagnose disorders (Alghamdi et al., 2022) [14].

The Effects of Gut Dysbiosis

Gut dysbiosis, an imbalance of gut microbiota, can harm health. Enteric pathogens cause intestinal inflammation and dysbiosis. Infection of the colonic epithelium by the opportunistic pathobiont *Citrobacter rodentium* causes gut inflammation and *E. coli* growth. Pathogen-unique outer membrane proteins that engage the TLR2 receptor on colonic epithelial cells, recruitment of CD11b+IL-22-group 3 innate lymphoid cells (ILC3s), and gut production of IL-6, TNF, and RSPO3 in neonates cause this expansion (Youn Yoo et al., 2020) [3]. Inflammasome signature gene expression increases tissue- and time-dependently with enteric infection, independent of Lamtor3 transcripts. In mice infected with enteric pathogens, like Escherichia coli NC101, caspase-1-mediated proptosis of colonic epithelial cells or macrophages (MΦs) occurs within 24 hours. Gpr83 gene expression is enhanced by TNF and IL-1R, as Tnf−/- and IL-1R−/− mice show lower Gpr83 expression after *C. rodentium* infection. DGEC, which can move from the gut lumen to the spleen and systemic circulation, can boost Eφ signalling via the NLRC4 inflammasome. Gut microbiota composition can increase certain taxa in inflammasome-deficient SPF Ctrl, but not to the level of Eφ−Sig Eco infection after WT Citro Eco infection. Validation of DGEC and DTE events in secondary gnotobiotic mice with extended Enterobacteriaceae consortium after Citro Eco clinical isolate and nonclinical isolate infection. Toxic C. difficile infection is a major healthcare burden for the elderly and immunocompromised, and increasingly virulent strains pose a public health risk. C. C. diff infection can come from broad-spectrum antibiotics destroying commensal bacteria whose secondary metabolites kill the pathogen. C. difficile toxins harm the intestinal epithelium, disrupting gut-associated bacteria and increasing gut permeability. Systemic inflammation and cytokine storm can emerge from intestinal damage-induced bacterial dispersion. C is overexpressed after antibiotics. difficile TcdA, TcdB, and CdtAB toxins in marmosets. Three of the five broad-spectrum antibiotics used in the marmosets' severe outcome group remove TcdA- and TcdB-producing microbiota. Antibiotic-induced gut microbiota disturbance can promote pathogenic C. difficile and intestinal damage. Nonspecific gut injury treatment leads to systemic bacterial spread.

Gut Dysbiosis Causes

Many factors can cause intestinal dysbiosis. For instance, commensal bacteria co-aggregate with diseases to decrease replication, but medications eliminate them, allowing the antibiotic-resistant pathogen to flourish. C. difficile toxins break the epithelial barrier and induce intestinal permeability. Due to increased gut permeability, infections can use nutrients reaching the gut lumen to fill a previously occupied ecological niche. Increased intestinal permeability also helps hosts access pathogens. Increased gut permeability to LPS enhances LBP binding and IL-1β release, promoting hemophagocytosis. Pathogen-induced gut inflammation benefits pathogen growth by generating iNOS molecules in host innate immune cells. Pathogen infection converts pro-IL-1β into active IL-1β, promoting neutrophil recruitment and pathogen elimination. The literature provides numerous examples of gut microbe-immune system interactions that boost colonization as part of a cascade. Bacterial toxins can activate caspase-1 and release mature IL-18 and IL-1β via stimulating the NLRP3 inflammasome. Gut microbes can potentially exploit immune responses from unrelated coinfections. The fungal microbiome activates the IL-22 pathway to release GZ into the luminal space, promoting P. aeruginosa colonization (Youn Yoo et al., 2020) [3].

Health Effects of Dysbiosis

The innate and adaptive immune systems shape the gut microbiota. However, the immune system relies on the gut microbiota for proper fitness, making their interactions complicated and bidirectional. There are various gut immune systems that modulate gut microbiota. Mice lacking CD40L lymphocytes have thicker colonic mucosa, better barrier function, and less commensal bacterium gut penetration. Inducible T-cell co-stimulator, another co-stimulatory receptor up-regulated on B cells by a specific T helper cell subset, decreases IgA-coated bacteria in its KO mice. Segmented filamentous bacteria, adherent species that strongly affect small intestine IgA responses, develop uncontrollably in these KO mice. T cell reduction in Peyer's Patches increased SFB colonization, Th-17 response, and small intestine mucus layer thickness, "locking" the SFB at the brush boundary and causing systemic consequences. Apoptotic macrophage depletion increases commensal IgA responses, shaping gut microbiota. Chronic antigen exposure induces IL-10 in T cells, which generates tolerogenic signals. Short-chain fatty acids from dietary fibers maintain gut mucosa homeostasis, reduce T cell-driven inflammation, and differentiate T regulatory cells. Thus, a specific microbiota fraction in a gastrointestinal compartment may operate as a persistent source of antigen, activating antigen-specific T cell responses. To reduce inflammation and avoid more violent immune responses, antigen-specific T cells can send tolerogenic signals to other immune cells.

Cancer patients receive a lot of antibiotics, which affect the gut flora quickly and permanently. Cancer patients undergoing hematopoietic cell transplantation with oral antibiotics and without antibiotics were compared for gut microbiota alterations. Antibiotics reduced bacterial taxonomic diversity and increased pathobionts, including mucosal barrier-breaching pathogens. However, the patient group without antibiotics and HCT had intact alpha diversity and a high relative abundance of commensal/neutral microbes and bacteroidales, which maintain gut sterility. Then, despite ongoing oncological compromises and immunosuppression from the HCT, the patient group that did not receive further antibiotic treatment had a stable gut microbiota profile, suggesting that antibiotics in cancer patients may cause complex GVHD and its high mortality.

Gut Health Improvement Methods

Certain foods can boost the immune system and gastrointestinal health. According to a study, eating more garlic, onion, broccoli, and green tea improves intestinal health. Most recommended are fiber-rich foods. Pure psyllium fiber dissolves in water. Consuming psyllium boosts gut bacteria and reduces germs. Enoki and oyster mushrooms may reduce cholesterol and intestinal bacteria. Hibiscus, raspberry, oolong, and black tea boost intestinal microbes.

Some meals urge modifying habits for gut and overall health. Fats are unhealthy. Consuming too much fat suppresses beneficial bacteria, which can cause digestive diseases (Shang et al., 2024) [5]. The recommended daily fat intake is 44 grams. Fast food restaurants usually serve at least 60 grams of fat per fried chicken, burger, or French fry. Fattening food can promote diabetes and obesity.

Replace nighttime soda with juice or coconut water. Soda's low pH erodes the stomach lining and tooth enamel. Long-term usage of sugary drinks causes obesity and renal damage. Green tea is also advised since several studies found high antibacterial capabilities to fight *E. coli*, *Shigella*, or *Salmonella.* Consume more fruits like papaya, pineapple, and guava daily. They are rich in vitamin C, which can improve health.

Probiotics

Recent research suggests that a healthy immune system is essential for infection prevention and treatment. We don't want to increase or suppress immunity, which is defined as boosting or suppressing immune response components. We want to activate the immune response during an illness and therapy with vaccines or antimicrobials to activate the cellular mechanism that attacks and removes bacteria. However, excessive immune system activation can harm the host in many infectious disorders, especially those caused by organisms that can cause ectopic infection, such as Salmonella and other intracellular parasites like Leishmania. The immune response begins with phagocytic cells activating by recognizing conserved microbial features after harmful germs pass natural barriers. Activated cells produce many bactericidal proteins and oxygen/nitrogen reactive substances to kill microbes. MAMP-elicited signalling activates all three pathways, increasing microbicide capacity and killing pathogens that can travel from the infection site.

Probiotics are "live microorganisms that can provide benefits to human health when administered in adequate amounts." The immune system has the largest interface with the body's external environment in the gastrointestinal (GI) tract, a complex ecosystem. MAMP-elicited signalling affects epithelial cytoprotecting, survival pathways, and barrier function. Pattern recognition receptors (PRRs) are essential for a healthy gut-microbiota connection, according to several studies. Innate immunity components, intestinal epithelial cells (IECs), or gut-resident monocytes and macrophages, express most TLRs. TLR activation upregulates pro-inflammatory genes that are post-transcriptionally processed and released as physiologically active soluble proteins. Mice treated with TLR agonists or MyD88-targeting siRNA were more susceptible to enteric infections. TLR agonists may have complicated modes of action that involve direct and indirect effects on various target organs and effector mechanisms, and probiotics may benefit GI illnesses through multiple routes.

Foods Prebiotic

Diet provides important nutrients for tissue and immune system health. Deficiency conditions can increase infection risk, although well-nourished people may be more susceptible. Infant malnutrition may decrease immune function, and obesity is linked to frequent infections. The outcome of competition is complicated since optimum immune responses to infection require increased availability of nutrients, including energy, and some immune responses consume nutrients. Thus, nutrition can affect immune function, especially in the gut, where most of the immune system is. A recent gut health study found that "there is substantive evidence for the ability of diet to modulate immune activity within the gastrointestinal tract". The food may affect gut immune activity since most gut immune cells are in the lamina propria and Peyer's patches, where they can sample luminal contents. In addition, up to 70%

of the body's immunoglobulin-producing cells are in gut-associated lymphoid tissue (GALT), where 800–1000 Peyer's patches sample dietary and microbial antigens to distinguish harmful pathogens from harmless ones (Hardy et al., 2013) [15]. Thus, the diet can affect gut immune function through many mechanisms, including antigen absorption, antigen-presenting cell number and type, gastrointestinal transit rate, gut flora, and epithelial cell permeability. Some meals have bioactive ingredients that significantly promote favourable immune responses. In theory, the immune system can be stimulated by providing "psychological" immune enhancement, improved nutrition for those with poor nutritional status, or dietary factors that directly stimulate immune system cells and components. The latter path is most interesting. Given the large number of immune cells in the gut lumen and the fact that food and microbial antigens can activate the immune system, the gut lumen may contain the most immunostimulatory dietary agents (T. Vieira et al., 2013) [16]. Immunonutrition refers to nutrients and dietary components that can regulate immunological function. Fermented milks and their bioactive peptides, which have immunomodulating and immune-stimulating properties, are of great interest to immunocompromised people.

Several food components have been proven to alter immune function in formal investigations. Most research on immunostimulants has focused on nutrient supplements and functional foods, with considerable dispute about what defines an immune-boosting food. Much research has examined how a functional meal or isolate designed to boost the immune system affects an immunological response. Prebiotic and probiotic foods, herbs and spices, glucans, flavonoids, tea catechins, fish oil, and FAs have been shown to modulate the immune system. The immune system interacts with nutrition in 5 ways. Nutrient malabsorption can affect the immune system, especially if a nutrient is essential. Second, food antigens can trigger immune responses in autoimmune or mucosal barrier-compromising diseases. Thirdly, long-term antigen exposure might cause immunopathologies due to antigen/antibody complex buildup. Fourthly, some nutrients can directly or indirectly affect the immune system, making hyper-supplementation as harmful as a lack. Finally, gut commensals and pathogens can activate local immunity. In the gastrointestinal tract, where nutrition meets the immune system, this is crucial. Bioactive phytochemicals may protect against oxidative cell damage and alter cell-mediated immune responses.

Lifestyle Changes for Gut Health

Well-established links exist between food, gastrointestinal health, and immune function. Nutrient-dense diets promote gut bacteria, but unhealthy one's cause gut problems. There are many lifestyle adjustments that can improve gut health.

Eat a variety of plant-based foods. Plant-based diet advocates say a mix of plant-based foods improves intestinal bacteria. Plant meals provide fiber and polyphenols that benefit the gut microbiome, according to research. Diversifying plant foods is a good start, but there is not enough information to recommend one diet over another.

Fiber fuels gut beneficial bacteria. Gut bacteria ferment cellulose into short chain fatty acids. Short-chain fats support the intestinal lining and prevent pathogen growth. This strengthens the gut wall barrier against pathogens. A high-fiber diet has been shown to change the gut microbiota to beneficial bacteria. For gut health, fruits, vegetables, legumes, and whole grains are great sources of fiber.

High animal protein consumption is associated with poor gut health, and animal fats can promote pathogen proliferation. In contrast, plant proteins benefit the intestines. Plant proteins, including nuts, seeds, and legumes, include fiber and polyphenols. Other foods, like soy, have fiber, flavonoids, and alpha amino acids. Gut bacteria ferment soy better due to its amino acids. Intake of soy protein improves gut flora composition.

New Research Directions

Diet's impact on gut microbiota composition and immunological function is crucial to our health. Understanding the linkages between diet, gut health, and immune function is expanding to combat today's unhealthy lifestyle, poor diet quality, obesity, and chronic diseases. This study area's major topics will be explored in detail below. These include the effects of phenolic compounds on gut commensals and potential pathogens, industrialization-driven food matrix modifications on metabolic and immune responses, food additives on immune responses and gut integrity, and dietary fibers on gut function and systemic metabolic activities. (a) Research on the complex interactions between food, gut microbiota, and immune function is growing (Meijerink et al., 2019) [17]. State-of-the-art systems biology-based tools, like in vivo and in vitro models, "omics-" platforms and algorithms can significantly advance our knowledge of immune system function and microbial communities (Shang et al., 2024) [5]. Research is now moving forward at an ever-increasing pace, with the discovery of new classes of compounds and an appreciation of the complex interplay between the hypothesized molecules.

New Gut Health Research Trends

Recent developments in gastrointestinal tract ecology have led to new research topics and health applications. Gastrointestinal health is tightly linked to the immune system and full-body health. The diet-gut microorganism-host tissue homeostasis system is crucial to human health. The gut microbiome is becoming recognized as a key component affecting health across systems. Understanding how nutrition and gut bacteria interact affects illness prevention, treatment, and health.

Emerging trends in gastrointestinal health research focus on diet-microbiota interactions, diet's effects on microbiota development and maintenance, microorganisms and metabolites from the gastrointestinal tract's effects on homeostasis, and microbe-host interactions' effects on immunity (Shang et al., 2024) [5]. This paper concludes with recommendations for future research, applications, and human health research objectives.

We incorporate the intricacies and dynamics of this interaction from recent diet-microbiota observational or human experimental studies to show how diet affects health by modifying gut microbiota composition. Few human intervention studies have systematically assessed dietary effects on gut microbiota, and the relationship between dietary intake and stool is complicated due to microbial compositional and functional dynamics throughout the gastrointestinal tract.

Possible Therapies

Several food components and diets can affect immune system-gut interactions and the controlled balance of pro- and anti-inflammatory responses. Food components typically need to be present at high concentrations without causing toxicity or other side effects. This concentration issue may be solved by targeting these "foods" as drugs, such as chemicals, in particular coloured fruit and vegetables that have health-promoting properties (Meijerink et al., 2019) [18]. Immunonutrition, which includes micronutrient supplementation with vitamins or minerals and food components with physiological bioactives, like carotenoids or polyphenols, is another approach that is gaining attention. However, nutrition has lately been found to greatly influence gut flora. Diet supplies substrates for gut bacteria to ferment into metabolites. Short-chain fatty acids are significant metabolites from dietary sources. Over 90% of SCFAs are acetate, propionate, and butyrate. These chemicals increase colon and systemic T-regulatory cells (Tregs), reducing inflammation. Recently, K. Singh et al. (2017) [18] confirmed that SCFAs affect the immune response in vitro under distinct inflammatory circumstances. This study also showed that the gut-brain relationship goes beyond how the microbiota may affect host systemic metabolite levels because specific bacteria produce neurotoxic metabolites that inhibit the host immune response. An important C. The difficile infection model showed that this work has consequences beyond host-microbiome interplay. Low-fiber/high-fat Western diets enhanced inflammation due to low SCFA levels, but diversified high-fibre diets were anti-inflammatory. Flavonoids and high fruit/veggie or Mediterranean diets considerably reduced inflammation. Inflammatory diets worsen CDI infections, creating a cycle of inflammation, impaired intestinal transit, and pathogenic microorganisms.

RESULTS AND DISCUSSION

Our research has revealed the complex link between food, gut health, and immune function, stressing the gut microbiome's role in immunological modulation. Several discoveries help explain how diet affects immune responses and gut flora.

Gut and Diet Microbiota

The gut microbiota's makeup and diversity depend on diet. Fiber, polyphenols, and prebiotic-rich diets encourage beneficial microbes, while high-fat, high-sugar diets promote pathogenic germs. A Mediterranean diet which emphasizes fruits, vegetables, whole grains, and healthy fats, like olive oil, has been linked to a more diversified and stable microbiome, which may boost immune function. Conversely, a Western diet consisting of processed foods, sweets, and unhealthy fats can cause gut dysbiosis, which can lower immune responses and raise inflammatory disease.

Immune Regulation and Gut Microbiota

The gut microbiome directly affects the immune system in various ways. Short-chain fatty acids (SCFAs), like butyrate, produced by beneficial gut bacteria, help maintain the intestinal barrier and regulate immunological responses. SCFAs increase anti-inflammatory cytokines and TREG differentiation, which modulate immunological tolerance and inhibit autoimmune reactions. However, an imbalance in microbiota composition can increase intestinal permeability ("leaky gut"), allowing bacteria and endotoxins to enter the circulation and cause systemic inflammation and immunological dysregulation.

Foods That Affect Immunity

Through their impact on the gut microbiome, several dietary components affect immune function. Fruit, vegetable, and green tea polyphenols have antioxidant and anti-inflammatory characteristics that alter immune responses. Omega-3 fatty acids, present in fish, inhibit pro-inflammatory cytokines and boost immune cell function. As a prebiotic, fiber, especially soluble fiber, promotes gut microorganisms that affect immunological responses.

In contrast, refined sugar and saturated fat diets hinder immunological function. Sugar increases harmful bacteria and decreases helpful microorganisms. A high-fat diet, especially one heavy in trans fats, increases systemic inflammation and immunological suppression, increasing the risk of obesity, diabetes, and cardiovascular disease.

Immune System Adaptation and Disease Prevention

Dietary therapies targeting gut microbiota may modulate immune responses and prevent immunological diseases. Probiotic supplementation restores gut microbial equilibrium and boosts immunity. Probiotics prevent and treat IBD, allergies, and respiratory infections, according to research. By supporting beneficial microorganisms, prebiotic-rich diets can boost probiotic benefits.

Many studies have shown that nutrition can prevent autoimmune disorders, allergies, and inflammation. Early dietary modifications, especially in children, may affect immune system development and minimize the incidence of allergic illnesses, including asthma and eczema. According to new research, individualized nutrition based on microbiome composition may be more effective at treating immune-related illnesses.

Chronic Disease and Gut-Immune System Crosstalk

Chronic illness immune response is regulated by the gut microbiota. Dysbiosis, sometimes aggravated by poor food, is associated with chronic low-grade inflammation-related diseases, such as cardiovascular disease, obesity, and type 2 diabetes. These disorders may be caused by gut microbiota-induced immune cell activation and cytokine production. Dietary treatments that target immunological dysfunction and lower chronic disease risk need to understand how nutrition affects the microbiome.

Future Clinical Applications and Perspectives

The rising corpus of research emphasizes dietary changes for immunological health. However, additional research is needed to provide dietary recommendations and understand how diet affects immune function. Clinical trials on the long-term impact of diet-based immune health therapies are needed to confirm observational data. Personalized nutrition based on microbiota and genetics is another promising study area.

CONCLUSIONS

Physiology, chemistry, and culture are often discussed separately in diet for health. It's unusual because nutritional components are the host's main physical interaction with the environment – food is digested, absorbed, and changed into metabolic response molecules. Complex, like ecology, it offers a vast spectrum of biochemical interactions between enzymes and substrates, hormones, minerals, lipids, amino acids, glucose, and microbiotics. Recent studies reveal the gut microbiota's crucial role in dietary digestion and metabolism. Diet can modify the microbiotic landscape and cause metabolic changes that might benefit or harm the host. Since most nutrients are biotic, any biological chemical can be a microbiotic factor, or numerous hostile and commensal bacteria can use it as food. Biotic refers to food and diet, specifically carbohydrates, proteins, and fats, often enriched with fiber, vitamins, minerals, and a wide range of bioactive micro- and macro-components. Recently, the food industry has offered processed, fortified, sugared, salted, and fatty foods. The most recent and important studies on nutrients and gut microbiota pathologies suggest a healthy diet classification that nearly matches the most possible food segmentation with the human gut microbiota.

The expanding corpus of evidence shows that nutrition affects gut health and immunological responses. A healthy gut microbiome, immune function, inflammation, and immunologically related disorders may be prevented or managed with a balanced, nutrient-rich diet. As research advances, probiotics, prebiotics, and functional foods may become essential to immune health management and disease prevention.

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