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Narrative Review of Microbiome in Malnutrition

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ABSTRACT

Malnutrition remains a major global health burden, disproportionately affecting children under five years of age in low- and middle-income countries. It is characterized by inadequate or excessive nutrient intake, leading to stunting, wasting, underweight, or obesity, with significant consequences for morbidity, mortality, and long-term development. Recent evidence highlights the role of the human gut microbiome as a central player in nutritional health, influencing nutrient absorption, immune responses, and metabolic pathways. Alterations in the composition and function of the microbiome, often referred to as dysbiosis are increasingly linked to undernutrition and overnutrition. Case studies in children and adults reveal that malnourished individuals harbor immature or disrupted microbiomes, with reduced microbial diversity, enrichment of pathogenic taxa, and impaired production of essential metabolites such as short-chain fatty acids and vitamins. These findings underscore a bidirectional relationship in which malnutrition shapes microbial ecology, while microbiome alterations exacerbate nutrient deficiencies and disease susceptibility. Interventions such as probiotics, prebiotics, dietary modifications, microbiota-directed complementary foods, and fecal microbiota transplantation represent promising approaches for restoring microbial balance and improving nutritional outcomes. However, challenges such as variability in research methods, ethical concerns, and limited evidence from large-scale trials hinder translation into policy and clinical practice. Advances in metagenomics, metabolomics, and culturomics provide new opportunities for understanding microbiome–nutrition interactions and developing targeted therapies. This review synthesizes current evidence linking the microbiome and malnutrition, discusses therapeutic opportunities, and emphasizes the need for integrated public health and policy strategies to reduce the global burden of malnutrition.
Keywords: malnutrition, gut microbiome, probiotics, prebiotics, nutrient absorption, and public health nutrition.

INTRODUCTION

Malnutrition constitutes a major public health concern, especially in the very young. Among developing countries, malnourished children experience higher morbidity and mortality and face increased risk for diseases later in life. It is broadly defined as a condition that hampers normal growth and development and manifests in either an excessive or insufficient intake of macronutrients and/or micronutrients; it also encompasses nutritional imbalances and clinical conditions that produce similar effects. Often, development entails deficits in growth velocity and bone growth [1]. Moreover, disruption of nutritional status during this phase increases the risk of developing metabolic and degenerative diseases such as diabetes, obesity, cardiovascular disease, osteoporosis, and nonalcoholic steatohepatitis. Therefore, malnutrition sets up a vicious cycle of recurrent infections and further deterioration of nutritional status [2].

Understanding Malnutrition

Malnutrition denotes a condition of inadequate intake or provision of essential nutrients, potentially manifesting as undernutrition, overnutrition, or micronutrient deficiency. Undernutrition encompasses stunting (impaired growth and development in children resulting from chronic inadequate nutrition), wasting (characterised by significant weight loss attributable to critical illness), and underweight (weight below age-specific normal thresholds), whereas overnutrition denotes nutrient intake exceeding bodily requirements [2]. Malnutrition perturbs a range of physiological mechanisms, including the endocrine system, insulin secretion, immune competence, and metabolic pathways, and constitutes a leading cause of morbidity and mortality worldwide. At present, 821 million individuals endure hunger and food deprivation [2]. Notably, over 45% of fatalities among children under the age of five can be ascribed to poor nutrition, whereas inadequate nutrient consumption among pregnant women and young children constitutes a precipitant of low birthweight, reduced immunity, restricted cognitive and physical development, heightened susceptibility to illness, and increased mortality risk. The premise that the composition of the human microbiome may be intimately involved in patterns of malnutrition is therefore deserving of circumspect examination [2].

Definition and Types of Malnutrition

Malnutrition refers to an excess or deficiency in nutrient intake relative to the body's needs [1]. Undernutrition (nutrient deficiency) and overnutrition (excess nutrient intake) are the two main types of malnutrition. Almost 50 million children under the age of 5 years suffer from malnutrition. Whereas overnutrition results in overweight and obesity, undernutrition has more severe consequences. It stunts child development, places people at higher risk of sickness and death, and constitutes an economic and sociological burden. In addition, malnourished children are more likely to suffer from infections and have impaired brain functions [2]. Nutrition constitutes a crucial link between the human host and the microbes inhabiting the body. Malnutrition and its associated negative consequences have been linked to alterations in the microbiome composition of affected individuals [1, 2].

Global Prevalence and Impact

Malnutrition affects people of all ages, but the prevalence is highest among children aged below 5 years, particularly those living in low-income and developing countries. In Africa and Asia, malnutrition accounts for nearly half of all child mortality [2]. In 2017, the United Nations Children's Fund (UNICEF) reported that a quarter of children under five years were stunted, and approximately 7.5% suffered from wasting 1. In addition to the high death rate, malnutrition during childhood exerts detrimental effects on physical and cognitive development and may even promote the threats of chronic diseases in adulthood. Malnutrition is widely defined as a pathological state caused by insufficient intake of dietary nutrients to meet the daily requirement based on age, body size, or health status [2]. The disease is divided into two major types: undernutrition (e.g., stunting, wasting) and overnutrition. In principle, an individual becomes malnourished when the daily energy consumption is lower than the daily energy expenditure due to a number of causes, such as infectious diseases and poor nutrient absorption. Since the microbiome contributes to nutritional status by regulating energy and nutrient absorption, malnutrition is therefore linked to altered gut microbial profiles [2].

The Human Microbiome

The human microbiome encompasses the vast ecosystems of bacteria, archaea, and viruses that colonize multiple anatomical sites in the body. It has extensive metabolic capabilities that complement those of the host. Microorganisms metabolize dietary components that are otherwise indigestible by the host into a range of molecules that drive host signaling systems. They help digest nutrients, such as indigestible plant polysaccharides and vitamin precursors, protect against infections, and educate the immune system [2]. The microbiome also plays an important role in regulating nutrient uptake and energy harvest. Emerging data also suggest a strong interaction between the microbiome and the immune system that influences the outcome of a range of diseases, such as cardiovascular diseases and autoimmune diseases that have metabolic components [2]. Emerging findings indicate that alterations of the microbiome may be implicated in the pathogenesis of malnutrition. Therefore, the composition of the gut microbiome and its changes in malnourished patients are now the focus of a broader effort to understand the pathophysiology of the condition and develop new treatment strategies [2, 1].

Composition of the Microbiome

The human microbiota comprises all microbes, their genes, and the surrounding environmental conditions within the human body. Approximately 40 trillion bacterial cells and as many human cells comprise the holobiont, with the gut microbiota constituting the largest collection of microorganisms [2]. The three main categories of microbes present within healthy human bodies are bacteria, archaea, and viruses. Bacteria comprise the vast majority, predominated by the bacterial phyla Bacteroidetes and Firmicutes, with Proteobacteria, Fusobacteria, Actinobacteria, and Verrucomicrobia constituting only a minor proportion, depending on the site of colonization. Archaea and viruses exist in far less abundance, with archaea comprising 0.1–1% of the human microbiota, mainly methanogens. Viruses colonize nearly all human tissues and can infect other associated microbes rather than humans themselves [1, 2]. Microbial communities are largely non-random in their structure, with each microenvironment supporting a distinct blend of species. Further interactions between the microbiota and their human hosts include various benefits such as the ability to aid digestion and absorption of certain polysaccharides, antagonize potential pathogens, and educate and modify the host's immune system, all of which can influence the host's physiology [1].

Functions of the Microbiome

The microbiota contributes a sizeable portion of the human body's energy-harvesting potential by extracting energy from dietary sources inaccessible to host digestive enzymes [2]. This contribution is crucial in nutritional states that require greater energy harvest, as observed in malnourished subjects. The microbiota also synthesises fatty acids and modifies bile acids that regulate host metabolic pathways, with the overall long-term outcome of coordinating energy uptake and expenditure. Malnourished individuals frequently exhibit an imbalance in the microbiota, characterised by pathobiont enrichment and a decrease in commensals and diversity. Specific alteration patterns differ between conditions, such as kwashiorkor and stunting, and can be influenced by environmental factors. These findings raise questions about causal relationships and the extent to which the environment determines microbial composition during malnutrition [2]. Longitudinal studies tracking gut microbial structure from birth are needed to clarify which microbial signatures fetter or reflect the development of malnutrition. For example, the altered microbiota of undernourished infants cannot be simply reproduced by dietary restriction alone, suggesting additional factors such as intrinsic undernutrition, pathobiont carriage, or environmental influences. An intact microbiota–host metabolism circuit has evolved in which short-chain fatty acids (SCFAs), vitamin synthesis, and bile acid conversion are key points of interaction that potentially anchor the host in a well-defined nutritional state and act as signalling hubs for adaptation to fluctuations in diet; the status of these key metabolites appears tightly coupled to malnutrition outcomes[2].

Microbiome and Nutritional Status

Diet-based influences on microbiota become relevant in the context of malnutrition. The gut microbiota aid digestion provides a barrier against infection, and support the development and organization of the immune system [2]. Consequently, malnutrition is likely to alter the microbiome structure. Undernourished children suffering from repeated diarrheal episodes or who are HIV-positive, for example, show greater changes to the microbiome. They often harbour microbiomes typical of younger children, with altered proportions of Bacteroidetes and other phyla [1]. Undernourished children with oedema, a marker of severe malnutrition that is commonly found in emergency settings, show more significant alteration, with a decreased proportion of Firmicutes relative to Proteobacteria.

Influence of Microbiome on Nutrient Absorption

The gut microbiota modulates nutrient absorption and energy storage by influencing dietary intake and feeding behavior. The composition of the gut microbial community is altered in undernourished children and adults 2. Undernourished children exhibit an immature microbiota incapable of energy extraction from the diet and nutrient synthesis adequate for normal growth [1]. Probiotics influence growth and modulate metabolism in undernourished animals and humans. High-protein and high-fiber diets restore excretory pathways linked to growth and development and mitigate pathogenicity in the undernourished [1].

Microbiome Alterations in Malnutrition

Malnutrition causes major changes in the gut microbiota, along with alterations in function and abundance. In malnourished individuals, microbial composition appears to be skewed, with decreased abundances of beneficial or saccharolytic microbes and increases in potentially pathological bacteria and methane-producing archaea [2]. These changes lead to a proinflammatory status and consequent shifts in the gut's physical or chemical environments. The exact nature of these alterations depends on local nutritional and environmental factors plus host characteristics, leading to similarly consistent malnutrition-associated microbiota changes at the species level despite region-specific differences [2].

Mechanisms Linking Microbiome and Malnutrition

A nutrient-rich milieu and a robust immune response are integral in modulating the abundance and diversity of the microbiome. Persistent interaction between the immune system and the microbiome mediates host immunological, metabolic, and neurological development [2]. Signalling pathways involved in the immune response further suggest how essential nutrients and biochemical metabolites from the microbiome affect microbe–immune system relationships. For example, a diet deficient in tryptophan decreases the availability of ligands involved in aryl hydrocarbon receptor activation, subsequently impairing the immune system's ability to generate tolerogenic responses to commensal microbes, thus diminishing the ability to eradicate invasive pathogens. This example illustrates how the depletion of a single nutrient can affect microbiome composition, function, and microbial tolerance at a systemic level. Consequently, the microbiome has implications for the regulation of both post-weaning nutritional flexibility and the management of gastrointestinal diseases in humans [1]. Several additional mechanisms also underscore the association between the microbiome and malnutrition, including energy regulation, immunological function, amino acid synthesis, and neural signaling [1, 2].

Immune System Interactions

A healthy gut must maintain a large surface area for absorption of macro- and micronutrients and an intact barrier that prevents translocation of pathogens or their products into the systemic circulation [3]. These processes are both impaired in malnourished individuals. Impoverished living conditions are characterized by widespread structural and functional abnormalities of the gut, alterations collectively termed environmental enteric dysfunction (EED). Repeated exposure to enteric pathogens is widely believed to be a major causative factor for the development of EED in environments of poor water quality and sanitation, although multiple causative factors are likely to be involved. Microarray analysis of intestinal biopsies from Malawian children with EED reported a cluster of immune-related gene transcripts correlated with intestinal permeability, consistent with a role for immune pathways in the development of gut dysfunction [3]. The microbiota, estimated to contribute between 20–30% of the overall energy supply in developing-country communities, performs a direct role in digestion by metabolizing macro- and micronutrients that the human gut epithelium is unable to process directly; microbial signals are essential for normal mucosal immune development and digestion. The microbiota, therefore, occupies a central position in the gut ecosystem, interacting intimately with ingested food and any contaminating environmental microbes or toxins. The composition of the microbiota is highly sensitive to changes in diet and therefore represents a high-fidelity sensor of dietary adequacy. Multiple trophic cascades occur within the gut microbiota in response to the presence or absence of different nutrient sources. Consequently, the availability of dietary protein, fat, and carbohydrates profoundly affects the microbial composition of the gut [3].

Metabolic Pathways

Biochemical reactions are commonly known as metabolic pathways, where one chemical compound undergoes chemical transformation in several steps, each catalysed by a specialized enzyme. Microorganisms possess an extensive range of metabolic pathways necessary for their life and growth, including both simple and interlinked complex cycles such as the Embden–Meyerhof pathway and the tricarboxylic acid cycle [2]. These pathways can evolve as biosynthetic routes to macromolecules like DNA, polysaccharides, proteins, or lipids, or function simply to gain energy [2]. Certain metabolic pathways are characteristic of specific microorganisms. Notably, some pathogens contain a combination of pathways not found in non-pathogenic bacteria, though this distinction is not consistent across all microorganisms. Microorganisms actively contribute to the metabolic capabilities of their hosts and can influence host metabolism through signals that alter gene expression, thereby affecting entire physiological systems [2].

Microbiome Interventions in Malnutrition

The discovery of the microbiome presents new possibilities for combating malnutrition through its role in digestion, immunity, and hormonal homeostasis 2. Malnutrition arises from an imbalance between dietary intake and bodily needs. A proteobacteria-driven microbiome has been observed in malnourished patients [1]. These findings have stimulated interest in intervening with probiotics and prebiotics to help restore the microbiome of malnourished patients [1]. Microbial intervention offers a viable strategy to restore the gut microbiome in undernourished children and adults, thus providing a potential remedy for malnutrition. Probiotics constitute a commonly investigated therapy for improving the nutritional status of malnourished individuals. Probiotic strains such as Lactobacillus reuteri and Lactobacillus rhamnosus GG are widely available and have been well studied. The mechanisms of action of probiotics include the competitive inhibition of pathogens, the production of antimicrobial compounds, and the maintenance of intestinal barrier integrity. Prebiotics can modulate and enhance the growth of beneficial microorganisms already residing in the digestive tract. Existing prebiotics primarily target a microbiome dominated by bifidobacteria and lactobacilli [1]. Alternative strategies for augmenting the microbiome of people living with malnutrition include the direct administration of the missing commensal bacteria, the transplantation of whole microbiomes, and the development of dietary supplements. A major technical challenge in the design of an effective intervention lies in the limited understanding of the structure and function of the microbiome associated with various forms of malnutrition. Hence, the composition of healthy microbiomes must be discovered alongside an understanding of the degree to which such a microbiome can be restored to guide the design of microbiome intervention therapy [1].

Probiotics and Prebiotics

Probiotics and Prebiotics Probiotics and prebiotics are promising components that promote health and contribute to a balanced diet by regulating the gut microbiota at different taxonomic and functional levels. Probiotics consist of living, non-pathogenic microorganisms able to modify the gut microbiota and thereby confer protection against disease [4]. These effects include improved immune and nervous responses, increased resistance against infection caused by pathogens, and maintenance of barrier functions in the gut. Probiotics may be able to restore disturbed metabolic stability, which is characteristic of malnutrition. Clinical trials of probiotic supplementation in malnutrition have focused on childhood malnutrition [4]. For example, resolution of underweight state in severely malnourished children has been observed with administration of various probiotic strains, including B. breve. Evidence from a limited number of studies suggests that probiotic efficacy may depend on dose selection, with consistent responses observed at particular doses across multiple trials. The nascent field of microbiome-directed foods, formulated to repair microbial immaturity, has yielded nutritional formulations that improve outcomes in children with severe acute malnutrition [4]. Probiotic supplementation reduces mortality and morbidity in preterm, low-birth-weight infants, indicating additional avenues for exploration in the treatment of undernutrition.

Dietary Modifications

Dietary modifications represent a prominent strategy for altering the microbiome in malnourished individuals. Probiotics, prebiotics, and changes in diet have been examined primarily in animal or observational human studies of microbiome-related illnesses. Rigorous research is necessary to establish the effectiveness of these methods for enhancing nutritional status [4]. Probiotics are live microorganisms that, when administered in adequate doses, grant a health benefit to the host, a concept dating to Metchnikoff in 1907. They are available in non-fermented foods, fermented foods, dietary supplements, and pharmaceuticals. Some of the most widely studied probiotic strains belong to the genera Bifidobacterium and Lactobacillus. Diet is a strong modifier of the gut microbiota, particularly in young children [1]. Targeting the gut microbiota with prebiotics, nondigestible food ingredients that stimulate the growth or activity of health-promoting bacteria, may offer an effective, affordable, and sustainable strategy for treating and preventing severe acute malnutrition (SAM), possibly by enhancing energy salvage through microbial fermentation and protecting against diarrhea [1,4]. Nevertheless, clinical evidence remains lacking, and further studies are needed to assess the impact of prebiotics on the gut microbiota and nutritional outcomes. Varying dietary patterns can induce significant changes in the microbiota. The composition of the gut microbiota depends on the balance of nutrient sources. Food insecurity, characterized by limited availability of nutrient-rich foods, influences diet and likely alters the gut microbiome. Adjusting diet in malnourished individuals may therefore hold promise for modifying the gut microbiota and improving nutritional status [1, 4].

Case Studies and Clinical Evidence

Microbial community alterations are associated with malnutrition. Malnourished children harbour gut microbiota of lower diversity than healthy children 1. The majority of observational studies report notably higher proportions of Proteobacteria in malnourished states, including kwashiorkor and micronutrient deficiency [4]. Methanobrevibacter smithii, a dominant human gut archaeon, is increased in anorexia nervosa and decreased in general malnutrition. In 2013, a study followed 317 Malawian twin pairs for 36 months, focusing on those experiencing discordant growth, including cases of kwashiorkor [4]. Fecal samples from children with kwashiorkor were transplanted into germ-free mice. Mice colonized with stool from kwashiorkor-affected children lost weight only when fed a Malawian diet, but not a nutrient-rich diet [4]. These results indicate that the microbiome contributes causally to acute malnutrition pathogenesis. A follow-up strategy involved using antibiotics and ready-to-use therapeutic food (RUTF) to treat affected children. Additional data confirm that RUTF substantially alters microbiomes in Malawi and Bangladesh. These findings emphasize the integral role of the gut microbiome in malnutrition and inform the development of more effective therapies [4].

Case Study: Malnutrition in Children

Malnutrition disrupts a child's growth and development [2]. It can be acute or chronic, with acute malnutrition's rapid weight loss being more concerning. Rising global prevalence and potential for inducing adult-onset chronic diseases underscore its severity [1]. Malnourished children exhibit severe microbiome alterations. Nutrition determines health through metabolic demands. Gut microbes process indigestible foods and regulate metabolism, immunity, barrier function, and behavior, making them integral to overall health and malnutrition a microbiome-related disease. Blood samples from rural and urban children in Sub-Saharan Africa with different nutritional statuses show that malnutrition correlates with specific microbial alterations [1, 2].

Case Study: Malnutrition in Adults

Adults experiencing various forms of malnutrition, including specific nutrient deficiencies and physiological alterations, compared to well-nourished controls, have exhibited physiological changes such as enlarged caeca, increased colon length, fatty livers, altered gut structures, and enlarged mesenteric lymph nodes [2]. Consistent with these findings, identical twins with discordant kwashiorkor displayed gut microbiomes that did not converge during a period of therapeutic food intervention; moreover, the gut microbiome of the malnourished twin induced weight loss when transplanted into germ-free mice, whereas the microbiome from the well-nourished twin did not [4].

Future Directions in Research

The burgeoning field of microbiome research offers promising avenues for advancing our understanding of malnutrition and its treatment. Technological innovations such as metagenomics, metabolomics, and culturomics enable comprehensive characterization of the microbiota, facilitating the discovery of critical components driving microbial alterations in malnourished states [2]. These developments pave the way for microbiome-targeted therapies, including dietary modifications, probiotics, prebiotics, micro- and macronutrient supplementation, and transplantation techniques, to restore healthy microbial communities and enhance clinical nutrition outcomes [1]. Future efforts might uncover microbial-based therapies capable of accelerating recovery from malnutrition across the life course. Despite these prospects, the application of microbiome-focused strategies in malnutrition faces several challenges. Variability in study populations, sampling approaches, analytical methods, and outcome parameters hampers comparability and interpretation of findings. Ethical dilemmas also emerge, particularly when considering faecal donor recruitment and microbiota transplantation in vulnerable groups such as children with severe acute malnutrition. Addressing these issues through standardized protocols and ethical frameworks is essential to realize the full potential of microbiome research in supporting recovery from malnutrition [1, 2].

Emerging Technologies

Emerging technologies, such as metagenomic profiling and animal models, have recently opened new opportunities to elucidate the association between microbiome and malnutrition [2]. Metagenomic approaches generate information on both microbial community structure and functions, enabling the characterization of the gut microbial community at more advanced resolution than 16S rRNA profiling. Mathematical models can assist in the interpretation of the large volumes of data generated. Germ-free animals colonized with human donor microbiota permit cause-and-effect relationships to be inferred: human gut samples from donors of different ages, geographical settings, and disease states (including malnutrition) are transplanted into these animals, reproducing the metabolic phenotypes of samples [2].

Potential Therapeutic Approaches

Therapeutic approaches targeting malnutrition encompass a range of interventions, including those aimed at the microbiome [2]. Microbiota-directed complementary foods (MDCFs) formulated to normalize the gut microbiota offer promising advances in diet therapy. Trials in Bangladeshi children demonstrated that MDCF-2 enhances microbiota composition and elevates health-relevant biomarkers; compared to Ready-to-Use Therapeutic Food (RUTF), MDCF supports superior physical, neurological, and immune development in cases of moderate acute malnutrition [2]. Antibiotics remain a component of treatment for approximately 10–15% of severely malnourished children who do not respond adequately to dietary interventions; third-generation cephalosporins such as cefdinir are effective in such instances. Amoxicillin and cefdinir have been linked to improved recovery rates, reduced mortality, and weight gain, and combinations of antibiotics can further increase survival probabilities [2]. Yet routine prophylactic antibiotic use in hospitalized children risks fostering resistant strains and may complicate recovery from malnutrition. Observational studies also connect antibiotic exposure to heightened risks of overweight and obesity; nevertheless, concurrent administration of penicillin and oligofructose has been shown to modulate gut microbiota in ways that protect rats and potentially their offspring from obesogenic effects. As childhood malnutrition rates rise, a comprehensive understanding of these and other emerging therapies becomes increasingly urgent [2].

Challenges in Current Research

The rapidly growing human population in recent years has resulted in a significant limitation of resources and services, such as food, water, and health care. As a result of an inadequate supply of services, the incidence of malnutrition has increased in recent years, resulting in development and progress being halted or reversed in many situations, especially in children [2]. Malnutrition can weaken the immune system, resulting in increased susceptibility to infections that exacerbate the problems. Despite recent studies demonstrating that the human gut microbiome is a key player in determining nutritional status, little is known about the links between malnutrition and the gut microbiome. This review outlines the current knowledge of interactions between the gut microbiota and malnutrition and discusses the potential of the microbiome for treatment [2]. The term malnutrition indicates an unbalanced nutritional state and means a mismatch between consumption and the body's demand for sufficient amounts of nutrients and micronutrients. Malnutrition is one of the biggest challenges for health care professionals worldwide. One way to split up malnutrition further is in undernutrition (undernourished), overnutrition (overnourished), and specific types of malnutrition, such as insufficient vitamins, minerals and/or other essential nutrients, or a combination of the above. The prevalence of undernourishment is 8.9% globally [1]. Malnutrition can be classified into disease or non-disease-related. Non-disease-related malnutrition can be caused by very low food availability, for example. Disease-related malnutrition can be a consequence of cancer, diabetes or tuberculosis. Regardless of which of the two types they belong to, the scenario will generally be the same: the body is not receiving enough nutritional components to maintain all of its stated and necessary physiological tasks [1, 2].

Variability in Microbiome Studies

Several pertinent factors causing variations in diverse microbiota studies have been identified, further complicating the assessment of malnutrition and the microbiome relationship. Studies are frequently constrained by limited sample sizes, thereby impeding the generalisability of findings. Geographic localisation contributes to additional variability introduced by region-specific influences, dietary customs, and lifestyle determinants [2]. Host factors constitute another source of disparity, with cohort characteristics such as age and overall health status exerting a profound impact on microbiota configuration. Methodological divergences related to the implementations of metagenomic investigations further undermine cross-comparability. Significant intra-group differences potentially reflective of fundamental biological discrepancies or extraneous confounders might yet be evident, the underpinning mechanisms lacking empirical corroboration. Syntheses supporting the contention that a dysbiotic gut milieu dominated by Bifidobacteria depletion constitutes a primary aetiological facet of childhood malnutrition are thus regarded as presently premature [2]. Nonetheless, trial outputs indicative of ecologically distinct configurations among cohorts with varying nutritional indices could prove instrumental in anchoring subsequent exploratory efforts focused on discerning microbial contributions to nutrient ecology and host physiological competence. Hence, a concerted endeavour directed towards elaborating expansive population-level surveys is warranted. These would ideally integrate comprehensive sampling designs, state-of-the-art omics modalities, and in vivo human experiments targeting remedial microbial interventions to alleviate or preclude manifestations of acute undernourishment 5. Integrated progress across this integrated programme offers substantial promise for informing more efficient mitigation strategies, thereby facilitating a transition from symptom-focused rehabilitation towards etiopathogenetically informed management. This illustrates a concerted transition that realigns contemporary aspirations towards optimised polity adaptations [2].

Ethical Considerations

Malnutrition and the concomitant changes in nutrient availability challenge the host microbiota, which in turn plays a fundamental role in the progression of the disease state, resulting in a range of adaptive and maladaptive consequences. Understanding the microbiome and its interplay with nutritional status and malnutrition is crucial in the context of public health and the future development of more effective treatments [1], particularly given the significant increase in the prevalence of malnutrition in recent years. Worldwide, millions of deaths can be linked to the wider consequences of malnutrition, including infection susceptibility, weight loss, or wasting [5, 7].

Malnutrition is the consequential effects caused by an imbalance in nutrient input and output, resulting in the improper functioning of the human body. It is a leading cause of mortality, with recent estimates showing an increase from 462 million to 821 million over 10 years. In its simplest form, malnutrition encompasses both undernutrition and overnutrition; undernutrition refers to a lack or insufficient levels of nutrients, while overnutrition involves excessive nutrient intake that can lead to overseas accumulation; either of these can lead to a state of malnutrition somewhere down the line [1, 5].

Public Health Implications

Lifestyle interventions are a viable option to optimize gut microbiota and alleviate malnutrition [1, 8]. The primary goal of such interventions would be to provide a more complete and balanced nutritional content, ultimately helping to reduce the clinical symptoms associated with malnourishment. These interventions include: (i) Select ingredients with modulatory effects on the microbial ecosystem (prebiotics), (ii) Add probiotic strains to promote changes in composition, (iii) Consider dietary strategies (e.g., higher fiber diet) alongside complementary treatments, (iv) Manipulate the "environment" of the GI tract to favor beneficial species. When applied in combination with standard malnutrition therapy, these approaches can potentially attenuate the severity of the condition during the critical recovery period. For more details, see also the section "Microbiome Interventions in Malnutrition." Considering the elevated prevalence of malnutrition in low- and middle-income countries (LMICs) and its multifactorial links with microbiome dynamics, current evidence supports a paradigm shift in nutritional policy towards a microbiome-focused perspective. In children five years and younger, the microbiome can be considered a determinant of nutritional status, mediating the risk of stunting and wasting through multiple pathways, across varying environments and ethnicities [6, 9]. When unknown factors such as excessive hygiene and environmental enteropathy substantially contribute to child malnutrition in problematic contexts, integrated interventions targeting both microbiome composition (using pro/prebiotics or dietary supplements) and overall sanitary conditions hold promise. The development and widespread implementation of these strategies should constitute policy priorities during the coming decade [6].

Policy Recommendations

Malnutrition, a major global public health crisis, currently affects over 925 million people worldwide. Children aged under five years are especially vulnerable, with malnutrition contributing between 30 and 50% of deaths. The gut microbiota has emerged as an environmental factor interacting with malnutrition, where diet strongly influences the gut microbial community structure and functions [1, 10]. During malnutrition, distinct alterations in gut microbiome taxonomic and functional profiles have been reported, pointing towards a contributory role in malnutrition development 4. Interactions between the gut microbiota and the immune system alongside effects on host metabolism represent putative mechanisms underpinning this link. Microbiome interventions in malnutrition therefore focus principally on the use of probiotics, prebiotics, and changes in dietary habits to restore a beneficial microbiome with a view to improving nutritional status. Recent advances in genomic and metabonomic technologies have furthered the study of the gut microbiome in human populations, uncovering potential roles in probiotic supplementation and the development of novel treatment strategies for malnutrition [1].

Community Health Strategies

Communities experiencing reduced access to essential nutrients and higher-than-average rates of malnutrition can be supported by implementing complementary nutritional strategies. Such approaches include restoring lactobacilli during food shortages and using prebiotics to encourage the growth of specific beneficial microbes. In conjunction with dietary change, either probiotics or prebiotics in the absence of probiotics can be used as strategies to encourage specific microbial regrowth to rebalance microbiota for improved nutritional outcomes [1, 11]. Probiotics are living microorganisms recognized for their health-promoting properties. They have been noted to increase nutrient bioavailability in hosts by producing enzymes that release nutrients from otherwise indigestible compounds [5]. This can be beneficial in undernourished hosts by increasing initial nutrient intake. Prebiotics, on the other hand, are non-digestible oligosaccharides that are fermented by beneficial microbes such as bifidobacteria and lactobacilli, promoting their growth and activity in the gastrointestinal tract. Complementary and alternative nutritional methods that include probiotics, prebiotics, and combinations of the two offer promising outcomes for the treatment of malnourishment during food shortage or nutritional deficiency [6, 12].

CONCLUSION

Malnutrition is a multifaceted condition with devastating impacts on child survival, growth, and development, as well as long-term risks for adult chronic diseases. Mounting evidence demonstrates that the gut microbiome plays a critical role in mediating nutritional outcomes, shaping nutrient bioavailability, immune function, and metabolic processes. Dysbiosis observed in malnourished children and adults reflects both environmental and dietary constraints and contributes to the persistence of undernutrition despite therapeutic interventions. Novel strategies, including microbiota-directed complementary foods, probiotic and prebiotic supplementation, and dietary adjustments, have shown encouraging results in modulating gut microbial ecology and improving recovery from malnutrition. Nevertheless, several barriers, such as heterogeneity of study designs, population-specific variations, and ethical limitations, continue to hinder widespread clinical application. Future research should focus on large-scale, longitudinal studies employing advanced omics technologies to establish causal links and define microbial biomarkers of nutritional health. Importantly, integrating microbiome-centered therapies into existing nutrition and public health frameworks could shift malnutrition management from symptomatic relief to mechanistic, evidence-driven approaches. Such integration offers a promising pathway to reduce malnutrition-related morbidity and mortality, particularly in vulnerable populations across low- and middle-income countries.

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