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Review

Time for food: The impact of diet on gut microbiota and human health

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ABSTRACT

There is growing recognition of the role of diet on modulating the composition and metabolic activity of the human gut microbiota, which in turn influence health. Dietary ingredients and food additives have a substantial impact on the gut microbiota and hence affect human health. Updates on current understanding of the gut microbiota in diseases and metabolic disorders are addressed in this review, providing insights into how this can be transferred from bench to bench side as gut microbes are integrated with food. The potency of microbiota-targeted biomarkers as a state-of-art tool for diagnosis of diseases was also discussed, and it would instruct individuals with healthy dietary consumption. Herein, recent advances in understanding the effect of diet on gut microbiota from an ecological perspective, and how these insights might promote health by guiding development of prebiotic and probiotic strategies and functional foods, were explored.

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Introduction

Food and nutrition are closely associated with human health. Much effort has been paid to unravel how nutrients and functional ingredients modulate human physiology and responses. During the last decades, because of the appreciation of the relatedness of microbiota with host health and diseases, there is growing interest in the mechanisms of how foods orchestrate the gut microbiota and hence influence host homeostasis. Food is the primary source of energy for the gut microbes, and changes in host dietary patterns can result in rapid changes in the population structure of the microbiota [1]. Research has indicated that diet can greatly influence the gut microbiota composition, which in turn affects the host's health profoundly. Dietary changes can account for up to 57% of gut microbiota changes, whereas host genes account for no more than 12% [2]. Diet reproducibly alters the gut microbiota of mice with diverse genotypes. The gut microbiota exhibits a linear dose response to dietary perturbations, although after perturbation, most bacterial taxa reach a new steady state in 3 d [3]. Such diet-induced changes to gut-associated microbial communities are now suspected of contributing to increasing epidemics of chronic illnesses both in the developed and developing world, such as obesity and inflammatory bowel disease. Long-term dietary intake influences the structure and activity of the trillions of microorganisms residing in the human gut. Similarly, short-term consumption of diets composed entirely of animal or plant products also significantly alters microbial community structure and overwhelms interindividual differences in microbial gene expression [4]. Over our history, humans have experienced major dietary changes from gathered to farmed foods during the agricultural revolution and, more recently, to the mass consumption of processed foods in the industrialized world. Each dietary shift was probably accompanied by a concomitant adjustment in the microbiota. Nevertheless, diet-induced extinctions in the gut microbiota compound over generations [5]. On top of that, many chronic diseases have been attributed to a decreased diversity of gut microbiome, including diabetes and inflammatory bowel disease. Moreover, host diet is known to alter microbiota composition, implying that dietary intervention might alleviate diseases arising from altered microbial composition. Meanwhile, individual diet has been reported to have sex-dependent effects on vertebrate gut microbiota.

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Consequently, treatment of microbiota-associated diseases might need to take into account these interactions, potentially requiring therapies tailored to host sex and possibly other aspects of host genotype [6].

The mammalian gastrointestinal tract is a complex environment where bacterial-host associations are paramount. The human gut harbors diverse microbes that play a fundamental role in the well-being of their host. The constituents of the microbiota have been found to interact with one another and with the host immune system in ways that influence the development of disease [7]. It is now appreciated that in addition to providing nutrients and vitamins, the microbiota affects the host's metabolism, immune and digestive systems, behavior, and neurologic diseases [8]. In particular, the composition and metabolite profiles of gut microbiota have been associated with pathogen resistance, inflammatory responses, and adiposity [9]. In return, the microbiota derives benefit from the association with its host by inhabiting a nutrient-rich environment. This mutually beneficial or mutualistic interaction relies on a homeostatic host/microbiota relationship that depends on two main parameters: the intrinsic capacity of microbes to colonize and persist in the host and the host's ability to tolerate and control them [10]. Recent sequencing efforts of the human meta-genome have changed our understanding of the microbiome and how variations in these populations can contribute to disease states [11].

The microbial community in the gut is shaped by what humans eat, and the community in turn shapes our development and health [12]. Dietary supplements with defined food ingredients that promote particular components of the microbiota may prove useful for maintaining human health. On a community basis, microbiota profiling, potentially coupled with metabolomics, offers the potential for biomarker-based identification of individuals at risks for disease [13]. Here, the large body of data that is potentiating our understanding of how the food ingredients modulate the gut microbiota and how the gut microbiota alters the absorption and metabolism of food were reviewed. Given the interaction between the gut microbiota and food consumed, the aim of this review is to summarize the available evidence supporting the interactions between diet and the gut microbiota, as well as their plausible effects on health. A secondary aim is to seek dietary strategies that could modify the microbiota composition and improve human health.

Dietary modulation of the gut microbiota

Dietary fiber

Dietary fiber is known as microbiota-accessible carbohydrates (MACs). These carbohydrates are composed of monosaccharides that are connected through numerous types of glycosidic linkages and, in some instances, further modified by chemical substituents, such as acetyl and sulfate groups. The variation in their chemical composition, solubility, and size differentiates these carbohydrates into a vast array of ecological niches [14]. Trillions of microbes in the human large intestine—known as the microbiome—depend on dietary fiber to thrive and give us energy. Diet, especially consumption of dietary fiber, appears to be a critical determinant for gut bacterial ecology, diversity, and function [15].

Accumulating data suggest that host health is linked to dietary MAC-induced alterations in microbiota composition and diversity [14,16]. Daïen et al. [17] described low MAC consumption not only having detrimental impacts on gut microbiota in particular but also on the host as a whole. Also, low consumption of MACs over generations lead to the complete disappearance of beneficial bacterial strains in a preclinical study [17]. There is now overwhelming evidence of the health benefits of massive consumption of dietary fiber and its association with high concentrations of short-chain fatty acids (SCFAs) in the gut [18]. Chang et al. [19] found that dietary fiber from pear pomace prevented high-fat-diet–induced obesity in rats by improving the gut microbiota. Tan et al. [15] examined the beneficial roles of dietary fiber in peanut-based allergy in a mouse study. The authors found that this effect involved reshaping of the gut microbiota as well as increased levels of SCFAs and activity of their receptors GPR43 and GPR109a [15]. Lu et al. [20] described the participation of SCFAs for the prevention of high-fat-diet–induced obesity in mice by regulating G protein–coupled receptors and gut microbiota. Sivaprakasam et al. [21] reported that GPR43 had an essential role in dietary fiber–mediated promotion of healthy composition of gut microbiota and suppression of intestinal carcinogenesis [21].

Dietary fiber affects the gut microbiota composition, though large interindividual variations exist. Kovatcheva-Datchary et al. [22] revealed that participants with improved glucose metabolism after dietary fiber supplementation have increased the abundance of *Prevotella* in their gut microbiota. *Prevotella* plays a direct role in the beneficial response, supporting the importance of personalized approaches to improve metabolism [22]. In addition, dietary fiber with a specific chemical composition could be used to manage immune responses against pathogens such as *S. paucimobilis* [23]. It has also been found that dietary fibers have a potential to prevent high-fat-diet–induced obesity through modulating the gut microbiota [24]. Also, researchers indicated that cereal dietary fiber supplementation abrogated obesity-related liver lipotoxicity and dyslipidemia by modulating sterol-regulatory element binding protein pathway in C57BL/6J mice fed a high-fat/cholesterol diet [25].

Dietary proteins

Bacterial protein fermentation occurs in the distal colon and produces a variety of metabolites, including sulfur, N-nitroso, phenolic, and indolic compounds, as well as ammonia, organic acids, and heterocyclic amides, depending on the amino acid content of the proteins [26]. Dietary protein serves as the major source of nitrogen for colonic microbial growth and is essential to the assimilation of carbohydrates and production of beneficial products such as SCFAs. Hence, a combination of protein and carbohydrates in the large bowel can contribute to bowel health [27].

Dietary guidelines from medical literature and popular presses often promulgate high protein intake, especially from animal sources rich in essential amino acids, including sulfur-containing and branched chain, to combat obesity, sarcopenia, osteoporosis, frailty, surgical stress, and mortality. However, accumulating evidence points instead to a restriction of protein or specific amino acids in the diet as promoting health [28]. In recent studies that also addressed the impact of protein intake on the gut microbiota, high-protein diets were found to increase detrimental metabolites in feces. High-protein intake has also been connected to other diseases, even cancer. In a large prospective study, high intake of animal protein was associated with an increased risk of inflammatory bowel disease [26]. Ma et al. [29] described the importance of dietary strategies with judicious selection of source and supplementation of dietary protein to benefit gut health [29]. In addition, L-carnitine, an amino acid derivative and a nutrient in red meat, was recently reported to accelerate atherosclerosis

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