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Effects of High Dietary Fiber Intake on Glucose and Lipid Metabolism in Obese Individuals

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Abstract:

Obesity has emerged as a pressing public health concern worldwide, characterized by disrupted glucose and lipid metabolism. This dysregulation often results in severe conditions, including insulin resistance, type 2 diabetes, non-alcoholic fatty liver disease, and cardiovascular disorders. Besides genetic predispositions, unhealthy eating habits play a pivotal role. Recent research underscores the benefits of dietary fiber, an enzyme-resistant carbohydrate, in enhancing glucose and lipid metabolism. By incorporating fiber-rich foods into diets, individuals can mitigate these metabolic disturbances and work towards better health outcomes. comprehensively examines the impact of high-fiber diets on glucose and lipid metabolism in obese individuals, exploring the intricate physiological and molecular pathways involved. Dietary fiber alters the gut microbiota composition, fostering the production of short-chain fatty acids (SCFAs). These SCFAs bolster intestinal barrier function, enhance insulin sensitivity, and refine energy metabolism. Consequently, embracing a high-fiber diet emerges as a scientifically grounded and clinically valuable nutritional approach for managing obesity and associated metabolic disorders.

Keywords: High Dietary Fiber; Obese; Glucose; Lipid.

1. Introduction

Obesity defines a BMI of 25 kg/m^2 as overweight and 30 kg/m^2 as obese, highlighting the seriousness of this health issue. The frequency of world obesity has been increasing for recent decades regularly, being a serious danger for public health. The common causes of obesity are the joint action of several factors, such as heredity, unwholesome food habits, sedentary life, absence of physical exercise, psychological stress and social environments. Amongst others, namely unwholesome food habits, e.g. eating high-energy and high-fat, low-fibe food influences glucose and lipids metabolism conditions, deviating outside the normal levels, and represent important spheres for the activity measures. Numerous patients intend to lose weight using diet systems or other activities, but he/she is at the same time confronted with the problem of return to weight, thus not is effective with long term. The investigations that can be met show that by correct food frame, it is possible to effectuate certain measures pertaining to obesity. In this atmosphere, the effects of food fibers on the metabolic effects has been strongly researched. The fibers in food mass can be divided in insoluble food fiber and soluble food fiber: the insoluble standards mostly affect the stercoral transit speed, preventive function in the organism, at which increase in the stercoral material, cause intestinal movement, whereas soluble fibers are fermented by other commensal standard micro-organisms in colon, leading to a series of furthering of a series of useful metabolic products.

2. Impact of High Dietary Fiber on Obese People's Glucose Metabolism

2.1 Obesity's Impact on the Metabolism of Glucose

Insulin regulation is the main factor governing glucose metabolism under normal circumstances. Maintaining stable blood glucose levels is crucial for overall health, and insulin plays a pivotal role in this process. It works to suppress hepatic gluconeogenesis, the production of glucose by the liver, while promoting its uptake and utilization in peripheral tissues, particularly skeletal muscle and adipose tissue.

However, in obese individuals, excessive adipose tissue becomes problematic. This fat tissue releases free fatty acids and inflammatory factors, which interfere with insulin‘s signaling pathways, leading to insulin resistance. As a result, the liver produces more glucose, and peripheral tissues use less of it, causing blood glucose levels to rise persistently. Prolonged hyperglycemia not only puts additional strain on pancreatic beta cells but also increases the risk of developing type 2 diabetes.

2.2 Effects of High-Dietary-Fiber Diets on Glucose Metabolism in Obese Subjects

High-fiber diet demonstrates evident and significant effect on improving insulin sensitivity and glycemic control. The action of dietary fiber is multifunctional: First, soluble fiber forms viscous gel in the intestine that physically retards the absorption of glucose and, thus, in a practical sense, manages postprandial blood glucose [1]. Second, its metabolites regulate endocrine function. Evidence indicates that dietary fiber intake at high levels raises hepatic glucose metabolism enzyme activity, raises the density of insulin receptors on hepatocyte cell membranes, and consequently increases insulin affinity and enhances glucose metabolism Moreover, soluble dietary fiber in high-fiber diets gels in the intestine, and this slows down sugar absorption.Simultaneously, high dietary fiber inhibits the release of glucagon and gastrin and therefore reduces the burden on pancreatic beta cells. This elevates peripheral insulin receptor sensitivity, reduces insulin resistance, improves glucose metabolism, and contributes to the regulation of blood glucose [2,3]

An ultra-high-fiber diet intervention for 2 weeks of at least 55 grams per day of dietary fiber derived from whole foods in 20 obese adults (mean BMI 36.6 kg/m^2) with no diabetes was done. Results were that the insulin sensitivity index (Matsuda ISI, calculated through oral glucose tolerance test) was elevated by 32% on average following intervention. The level of fasting insulin among participants decreased dramatically from baseline of 20.6 μIU/mL to 14.7 μIU/mL by approximately 29% [4].

3. Impact of High Dietary Fiber on Lipid Metabolism in Obese Adults

3.1 Effect of Obesity on Lipid Metabolism

Obesity is intricately tied to dyslipidemia, characterized by heightened levels of triglycerides (TGs) and free fatty acids, along with decreased levels of high-density lipoprotein cholesterol (HDL-C). In obese individuals, the enlarged adipose tissue actively promotes triglyceride hydrolysis, which dumps substantial quantities of free fatty acids into the blood. These fatty acids are then reprocessed and excreted back into the bloodstream as very low-density lipoproteins (VLDL), ultimately contributing to an increase in plasma triglyceride levels. This metabolic imbalance underscores the complex interplay between obesity and lipid disorders.

In addition, blood lipid levels increase in proportion to the severity of obesity. At the same time, lipid metabolism disorders contribute to enhanced insulin resistance, which creates a vicious circle. Moreover, reduced levels of HDL-C decrease the body‘s ability to reverse transport cholesterol, elevating the risk of atherosclerosis and cardiovascular disease.

3.2 Effects of High-Fiber Diets on Lipid Metabolism in Obesity

It reduces extremely elevated triglycerides and LDL-C in obese patients and increases high-density lipoprotein cholesterol, thereby significantly improving the lipid profile. Dietary fiber, particularly soluble fiber, binds to bile acids and cholesterol in the bowel, facilitating their excretion. This leads to the liver being compelled to utilize more cholesterol to synthesize new bile acids, thereby actually lowering serum total cholesterol and LDL-cholesterol concentrations [5].

Visceral fat index is a significant measure that has been

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utilized to assess hidden obesity. Some evidence suggests that, following 12 weeks, a decrease of 7.4% in visceral fat and 5.2 cm in waist circumference were attained upon daily administration of 15 grams of soluble fiber (-glucan) [6]. Dietary fiber possesses an extremely intense hydrophilic character. When it is taken into the gastrointestinal tract, it rapidly absorbs water and expands, enhancing satiety and suppressing intake of other energy-yielding sources Repeated consumption effectively causes weight loss in the long term. Meanwhile, dietary fiber enhances adsorption and excretion of fat and intestinal cholesterol and reduces their absorption. Therefore, it controls total energy intake effectively, thereby causing weight loss. Dietary fiber soluble fiber binds with cholesterol and fat in the intestines, slowing digestion and enhancing cholesterol excretion. It keeps blood cholesterol in the normal range, reduces cholesterol and fat consumption, and improves lipid and obesity indicators.

A randomized trial of 20 obese adults (mean BMI 36.6 kg/m^2) on a two-week ultra-high-fiber whole-food diet consumed at least 55 grams of dietary fiber each day. Outcomes showed TC reduced from baseline 186 mg/dL to 161 mg/dL, a 13.4% reduction. LDL-C reduced from 112 mg/dL to 93 mg/dL, a 17.0% reduction. TG reduced from 135 mg/dL to 105 mg/dL, a 22.2% reduction [4].

4. The Connection Between Metabolic Health and Dietary Fiber: Gut Microbiota

The deeper benefits of high dietary fiber extend far beyond its physical effects, pertaining to its comprehensive value in regulating human metabolism and prevent chronic diseases. It not only augments energy intake through increased satiety, delayed gastric emptying, and reduced postprandial glucose levels, but also benefits the long-term control of weight, thereby lessening the likelihood of such metabolic conditions as obesity, type 2 diabetes, and cardiovascular disease. An increasing body of clinical and epidemiologic research evidence indicates that a high-fiber diet reduces all-cause death and improves public health, advocating its use as an integral part of chronic disease prevention and public nutrition policy.

Gut microbiota refers to the large community of microbes residing in the human gut, which includes bacteria, fungi, viruses, and other microbes. An ordered microbial community aids the breakdown of the unbreakable components like dietary fiber, produces SCFAs, and encompasses immune modulation and metabolic regulation. Fiber diet selectively stimulates friendly bacteria to produce SCFAs and other beneficial health-enhancing metabolites. They exert direct regulation over lipids in the blood and glucose, ultimately playing an important part in maintaining healthy lipid and glucose metabolism.

4.1 Central Mediating Role of SCFAs

SCFAs are crucial metabolites produced by gut microbiota during the fermentation of dietary fiber. Among them, butyrate plays a pivotal role as the primary energy source for colonic epithelial cells, crucial for maintaining the integrity of the intestinal epithelial barrier.

It also prompts goblet cells to secrete mucin, strengthening the intestinal chemical barrier and safeguarding against „leaky gut“ and systemic inflammation. Furthermore, SCFAs stimulate intestinal L cells to release hormones like glucagon-like peptide-1 (GLP-1) and peptide YY (PYY). GLP-1 not only stimulates insulin secretion and inhibits glucagon release but also slows gastric emptying and enhances feelings of satiety. Meanwhile, PYY directly influences the central nervous system to suppress appetite, contributing to overall metabolic health.

SCFAs also promote systemic insulin sensitivity by stimulating glycolysis and glycogen synthesis and influencing hepatic gluconeogenesis. SCFAs acidify the colon, rendering it unfavorable for pathogenic bacteria More importantly, undissociated SCFA molecules can freely diffuse into pathogen bacterial cells, dissociate in the relatively neutral cytoplasm, release protons (H), favor intracellular acidification, and force pathogens to spend enormous amounts of ATP to expel protons, thus inhibiting growth or causing death [7]. It has been demonstrated that SCFAs activate fatty acid -oxidation in the liver and muscle by inducing the AMP-activated protein kinase (AMPK) pathway. This accelerates the „burning“ of fat for energy rather than storing it and thus reduces the level of circulating FFAs and relieves lipotoxicity [8].

4.2 Gut Microbiota Composition Redesign

The terminal gut microbiota of obese patients is typically dysbiotic, with reduced numbers of beneficialbacteria and increased numbers of pro-inflammatory or opportunistic pathogens. GORDON et al. contrasted 165 RNA gene sequences of terminal gut microbiota in 5,088 genetically obese and lean mice having the same diet. They saw 50% reduction in Bacteroidetes abundance and increased Firmicutes percentage in obese mice [9].

Dietary fiber at high levels selectively and dynamically remolds this structure. High-fiber diets have been shown to significantly enrich members of the families Muribaculacee and Muribaculacee. The former are dominant butyrate producers with the ability to produce butyrate from lactate and acetate through unique metabolic pathways, the latter are specialized at breaking down complex carbohydrates [10,11]. Moreover, long-term high-fiber diet treatment in mice has been reported by some studies to elevate the Bacteroidetes and Firmicutes bacteria while Proteobacteria is not affected Bacteroidetes are significant in degrading complex polysaccharides (more specifically those of plant origin), maximizing the host‘s utilization of nutrients. They also serve to increase intestinal mucosal angiogenesis, ecological balance, and immune system growth and development. Some members of the Firmicutes phylum are also major producers of SCFA.

5. Conclusion

A high-fiber diet exerts multidimensional and multilevel positive effects on improving glucose and lipid metabolism disorders in obese individuals. Its mechanisms extend beyond traditional physical effects (slowing absorption, increasing satiety) to profoundly influence core pathways through the „gut microbiota-short-chain fatty acids“ axis. This includes mediating improved insulin signaling, alleviating inflammatory states, and reshaping gut microbiota composition. Collectively, these mechanisms form the scientific foundation for high dietary fiber‘s efficacy against obesity and related metabolic disorders.

Notably, different dietary fiber types may exert distinct selective stimulation effects on microbiota due to their varying chemical structures, thereby influencing SCFA production and composition. This implies that future research and applications will trend toward precision nutrition-tailoring the most effective dietary fiber types and combination dosages based on an individual‘s unique gut microbiota structure to maximize health benefits. Therefore, appropriately promoting increased dietary fiber intake can become a core component of public health strategies and clinical nutritional interventions for preventing and managing metabolic diseases. Future efforts require more rigorously designed large-scale, long-term clinical trials and real-world studies to confirm the sustained benefits and feasibility of high-fiber diets across diverse populations. These studies should also delve deeper into the personalized effects of different fibers and advance the development and application of microbiome-based precision dietary guidance programs.

Authors Contribution
All the authors contributed equally and their names were listed in alphabetical order.

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