ISSN 2959-409X

Potential Application of Dietary Fiber in Improving Diabetes and Insulin Resistance

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Abstract:

The relationship between dietary fiber, short chain fatty acid (SCFA) and diabetes has been confirmed by some current studies. This article examined the influence of dietary fiber, a necessary type of fiber for the human body, on human Type 2 Diabetes Mellitus (T2DM), and how to manage the advancement of T2DM by converting it into SCFA by fermentation. This article introduces the fundamental connection between T2DM, dietary fiber and SCFA. It discusses the relationship between dietary fiber and body weight from various perspectives, as well as how the risk of obesity and T2DM is reduced by dietary fiber, manages insulin resistance, and enhances gastrointestinal flora. Adequate consumption of dietary fiber can help manage metabolic illnesses including obesity and T2DM, and SCFA play an important role in this process. This paper aims to clarify the relationship between T2DM and dietary fiber and SCFA, and inspire people to think about non-drug treatment methods for T2DM.

Keywords: Dietary fiber; Diabetes; Insulin resistance; Short chain fatty acids.

1. Introduction

Diabetes is an endocrine and metabolic illness primarily caused by insufficient insulin secretion and use, which includes type I and type II diabetes. Type 2 diabetes mellitus (T2DM) is a prevalent worldwide public health concern. More people are suffering from this sickness and its related issues. About 462 million people in the world suffer from T2DM, reaching an alarming proportion (6.28% of the global population). Diabetes causes about 1 million deaths every year, making it the tenth leading cause of death[1]. Thus, it is crucial to identify the factors influencing the development of diabetes. Insulin resistance (IR) is one of the important pathogenic factors that lead to human metabolic diseases, including T2DM. Insulin is the only hormone in the human body that can lower blood sugar, and it plays a key role in stabilizing blood sugar levels. The mechanism of insulin lowering blood sugar is to interact with receptors on cells, so that glucose in blood enters cells for oxidative decomposition and provide energy for cells. When IR occurs, insulin cannot perform the above physiological functions. The body is no longer sensitive to insulin, and the glucose in the blood cannot enter the cells smoothly and is consumed. In this case, the body needs to secrete more insulin to lower the blood glucose level. This indicates that IR increases the load of insulin secretion and strengthens the difficulty of blood sugar control[2].

Traditionally, dietary fiber (DF) has been defined as an indigestible component of plant-based foods; These include polysaccharide and lignin. Recently, this definition has been extended to include oligosaccharides such as inulin and resistant starch. In short, fibers can be divided into soluble fibers, such as sticky fibers or fermentable fibers (if pectin is used), and insoluble fibers, such as wheat bran, which have swelling effect but have limited fermentation in the colon[3]. Two types of DF provide significant health benefits, including anti-diarrheal effects, lowering blood cholesterol and triglyceride levels, reducing blood sugar in adult diabetic patients, and aiding in weight control. DF has a crucial role in shaping the microbiome's composition and metabolic functions, ultimately impacting the production of short chain fatty acids (SCFA) that are vital for intestinal health[4]. This article investigated how DF can enhance IR and diabetes, as well as its method of action.

2. Effect of DF on Improving Insulin Sensitivity

Insulin's ability to control blood sugar is compromised by IR, which is sometimes referred to as diminished insulin sensitivity (IS). It is the body's way of making up for too much energy. Consuming foods heavy in fat and sugar over an extended period of time, along with obesity, will put additional strain on the pancreas and require the secretion of more insulin to keep blood sugar levels in checkF. IR is probably the cause of T2DM and the metabolic syndrome. IR is defined as a reduced sensitivity of the target organ to the action of the hormone; in other words, less insulin is prescribed than would typically be necessary to provide a physiologically meaningful impact. IR is not only the cause of T2DM, but it also serves as the common pathophysiological basis for many other diseases.IS is used to express the degree of IR. The lesser the sensitivity, the less sugar is broken down and the stronger an effect insulin has. One of the causes of T2DM is low IS, and the other is insufficient insulin synthesis. When production reaches a sufficient level, it effectively treats diabetes by increasing IS. Increasing IS is a fresh idea in the study of hypoglycemic drugs. Hyperglycemia continuously stimulates insulin secretion, resulting in hyperinsulinemia, which can cause a number of changes like high blood viscosity, and type II diabetes patients are more likely to have decreased IS, also known as IR, which prevents insulin from performing its normal physiological function.

Additionally, by affecting protein absorption, cereal fiber may offer a novel method of enhancing IR. A high-protein diet raises the risk of IR and diabetes, according to numerous studies[5, 6]. By obstructing the absorption of dietary protein, consuming more high-insoluble cereal fiber can enhance IR and lower the risk of T2DM. The studies of Wachter Martin O., Roden Michael, and others provide evidence in support of this theory. From the Berlin-Potsdam Metabolic Syndrome Study cohort, 2700 participants were enlisted. The results of the experiment show that the individuals' systemic IS was effectively improved and their insulin-mediated glucose intake increased from 4.09 0.37 mg kg 1.1 (week 0) to 4.61 0.38 mg kg 1.1 (week 6) when they were given a high-fiber diet. After eighteen weeks, the IS improved by sixteen percent above the baseline value[5]. Edible plant protein is more beneficial in avoiding IR and T2DM than meat protein is. This is due to the fact that a diet high in plant protein typically has a high DF content, which in this instance has a protective impact on the human body. For instance, there is a 5% increase in the risk of T2DM when 1% of the energy in carbohydrates is substituted with 1% of the energy in protein. However, this danger can be substantially reduced thanks to DF intake. The incidence of T2DM is lowered by 18% when the energy in 1% animal protein is replaced by the energy in plant protein. There will be a 17% decrease in the chance of T2DM for each5 g increase in plant protein intake[6].

Intestinal microbes break down DF through fermentation to create several SCFA, including acetate. enhances the secretion of intestinal hormones, promotes fat burning, and boosts energy consumption. Overall, these actions can improve adipose tissue's capacity to store fats, control hunger, and break down substances, leading to improved function of peripheral tissues and overall IS. Additionally, enhancements in insulin levels and glucose regulation were observed with vinegar treatment. Previous research has demonstrated that consuming vinegar orally, with 4%-8% acetic acid, can rapidly increase the concentration of acetic acid in the bloodstream. When combined with carbohydrates (50-75g), this can effectively reduce blood sugar levels and insulin response. Oral vinegar showed enhanced insulin levels and glucose regulation in healthy participants compared to colon sodium acetate infusion[8]. For example, assessing meals in healthy individuals and adding acetic acid (unspecified vinegar) can lead to a reduction in post-meal glucose levels (about 35% after 30-70 minutes), probably via slowing down stomach emptying[9]. Administering white vinegar at concentrations of 18, 23, and 28 mmol/L, combined with 50 g of white wheat bread, to healthy persons will reduce insulin levels and blood sugar levels within 30-45 minutes.15 to 30 minutes after consuming the meal. Moreover, acetic acid can increase feelings of fullness and reduce blood glucose levels at 30, 90, and 120 minutes post-meal[8]. A study with healthy participants discovered that incorporating vinegar juice with potato powder, consisting of 28 grams of white vinegar with 6% acetic acid, resulted in a reduction of the glycemic index by 43% and the insulin index by 31%[10]. Acetate infusion and vinegar administration have been reported to have positive effects on glucose regulation and potential IS.

3. Effect of DF on Blood Glucose Control

Diet is considered to influence the condition of T2DM. The low glycemic index (GI) diet contains a lot of DF and least processed whole grain products. Studies have proved that this has a positive control effect on controlling blood sugar concentration and slowing down the rise of blood sugar. According to the experiments made by Knowler, W.C., Barrett-Connor, E. et al., the lifestyle intervention group's incidence of diabetes decreased by 58% compared with that in placebo group. In the past four years, the T2DM's cumulative incidence was only 20%, while the incidence for the placebo group was as high as nearly 40%, which was twice as high as that of the lifestyle group[11]. The ability of DF to delay food digestion and nutrient absorption has an important impact on the metabolism of lipids and carbohydrate. Some foods that are not especially rich in fiber can also play the beneficial role of high-fiber foods. The fiber content and physical morphology in food will affect the absorption of nutrients by digestive enzymes, thus delaying digestion and absorption. High fiber content in food means that the digestion and absorption speed of food will be greatly reduced. And solid food takes much longer to digest than liquid food[12]. DF has the ability to absorb organic compounds like bile acid cholesterol, leading to a reduction in blood cholesterol levels. Furthermore, it can also slow down the uptake of glucose and regulate blood sugar levels. Manuel A. González Hernández et al.'s experiment demonstrated that individuals with T2DM who consumed a high-fiber diet, which included traditional Chinese medicine food and prebiotics, for 12 weeks exhibited greater enhancement in blood sugar regulation (HbA1c < 7%) compared to those on the control diet (89% and 50% respectively)[13].

4. Effect of DF on Lose Weight and Reduce the Risk of T2DM.

One of the main reasons for increasing the incidence of T2DM is obesity. Studies have shown that children who are much heavier than normal teenagers are much more likely to have T2DM[14]. The speed of metabolism will affect the speed of decomposing and absorbing carbohydrates and fats in the human body. Fast metabolism means that the human body can digest, absorb and consume energy faster, which means that the energy in the body can be consumed faster. At this point, when the nutrients in the daily food are completely digested, absorbed and consumed, the energy stored in the body begins to be consumed, which means that the human body begins to lose weight. Some main symptoms of obesity can be alleviated by eating more DF. Not only that, the risk of T2DM will be greatly reduced.

DF can effectively slow down the weight gain, thereby reducing the incidence of T2DM and controlling the disease. DF has strong water absorption, which can absorb 5-10 times its own weight after entering the human body. After absorbing water, it expands into a gel, which increases the viscosity of food and the feeling of fullness. It reduces people's desire to get food again, and effectively helps people to control their appetite and then lose weight. The application of acetate produced by microbial fermentation of DF may affect weight control by affecting energy intake and consumption (Fig. 1). Den Besten et al. observed that oral sodium acetate supplements were added to the diet (5%, weight/weight) in a 12-week intervention in mice fed a high-fat diet[15]. Inhibited weight gain (~30%) was observed as compared to control mice fed an HFD[15]. According to Lu et al., oral sodium acetate supplementation for 16 weeks (5%, weight/weight) A 72% ($P < 0.05$) reduction in the weight gain caused by HFD was seen in comparison to control mice who were fed the same diet[16]. Additionally, mice fed an HFD for six weeks were administered acetic acid (50,250 mmol/L) in comparison to HFD alone. This prevented the mice from gaining weight (7% and 8%, respectively) and from accumulating body fat[17].

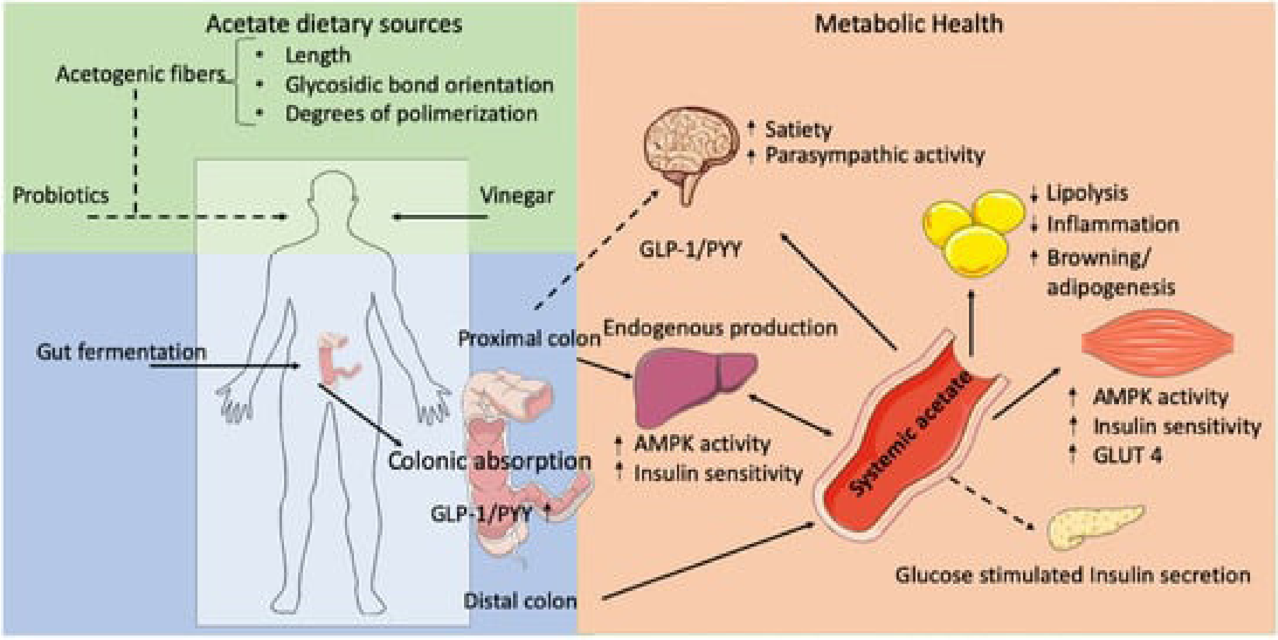

Fig. 1 The effect of acetate administration on human body[18].

5. Effect of DF on Improve Intestinal

Microbial Composition

The human intestine contains many microorganisms and most of them are bacteria. A healthy adult‘s intestines can contain up to 1-1.5 kg of bacteria overall, and there are roughly 10 to the 14th power.10 times as many bacteria in the intestines as there are human cells[19]. In 2006, Jeffrey Gordon of the University of Washington School of Medicine and others discovered that the bacteria in the intestines of obese people were very different from those of slim people. The former‘s microbiota is actually helping obese people to get fat. This kind of bacteria will absorb too much heat from food, which will be digested and absorbed by the body, thus depositing excess fat. Gordon and others collected and extracted the bacteria from the feces of 12 obese volunteers, identified different bacterial species by genetic sequence, and finally compared them with the bacteria in the feces of 5 thin volunteers. Most bacteria in these two groups of volunteers can be divided into two categories. One is the phylum Firmicutes, including Listeria, Staphylococcus, Streptococcus, etc. The other big category is Bacteroides. The results showed that the thick-walled bacteria of obese people were about 20% more than those of thin people, and their Bacteroides were about 90% less than those of thin people. The intestinal flora in obese individuals is less diverse compared to that in normal individuals, suggesting a significant impact of intestinal flora on obesity[20]. Intestinal flora significantly influences the development and progression of T2DM due to its strong connection with obesity. Imbalance in diabetes patients disrupts the diversity and stability of gut flora. DF can enhance the quantity and quality of gut bacteria. DF can be fermented in the colon, resulting in the production of SCFA. SCFA can lower the pH of the stomach and intestines, creating a mildly acidic environment in the intestine. Low acidity promotes the growth and reproduction of good bacteria while hindering the proliferation of dangerous bacteria. The intestinal flora can be adjusted and strengthened in an objective manner.

More and more data show that SCFA has a beneficial effect on the metabolism and function of skeletal muscle, liver matrix and adipose tissue, and finally IS can be improved[21]. DF can be digested into SCFA in the gut, which can stimulate insulin release in the intestine and enhance IR. The primary SCFA are acetic acid, propionic acid, and butyric acid. Bacteria provide the human body with 10% of its daily energy through the absorption of acetic acid. Propionic acid is broken down and processed in the liver after being absorbed into the bloodstream. It plays a role in the conversion of pyruvate to glucose and may hinder fat formation. Epithelial cells primarily utilize butyrate as their main energy source.

When the body consumes a significant quantity of soluble fiber, intestinal microbes digest these DFs into SCFA , primarily acetate, propionate, and butyrate. SCFA will participate in the host’s body metabolism and have a significant impact. SCFA are delivered into the systemic circulation and can impact the host’s metabolism via binding to G protein-coupled receptors[22]. SCFA can enhance energy expenditure and stimulate the secretion of anorectic hormones, therefore improving appetite regulation[21]. Acetate promotes the release of intestinal hormones including GLP-1 and peptide YY, which positively impact the host’s energy and substrate metabolism, therefore influencing hunger by decreasing systemic lipolysis. Simultaneously, it can decrease the presence of pro-inflammatory cytokines throughout the body while enhancing energy expenditure and fat oxidation[18].

6. Conclusion

The link between DF consumption and the prevalence of T2DM is complex and multimodal. Research shows that there is a negative correlation between the intake of DF and the risk of developing type 2 diabetes. Studies have shown that consuming more DF can aid in weight management and reduce the occurrence of obesity, a significant risk factor for type 2 diabetes. DF can ferment into SCFA , potentially reducing type 2 diabetes by improving IS and managing IR. The fermentation of DF produces SCFA that can promote the growth of beneficial bacteria and inhibit the growth of harmful bacteria in the gut. Restoring variety and balance in the gut microbiota can have a beneficial effect on the health of persons with T2DM.

Previous research on the correlation between overall DF consumption and blood sugar regulation has produced conflicting findings. The inconsistency may be due to the difficulty in controlling for concurrent changes in macronutrient intake, which complicates the appropriate interpretation of the data. The particular processes responsible for the positive impact of increased fiber diet on blood glucose regulation are not yet fully understood. It is unclear if soluble fiber, insoluble fiber, or both are responsible for these effects. Future research could concentrate on studying soluble and insoluble DF independently to ascertain their individual effectiveness in regulating blood sugar and clarify their distinct mechanisms of action.

DF consumption shows potential in managing T2DM, but additional research is required to comprehensively grasp the intricacies of this connection and enhance dietary guidelines for persons with the condition.

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