

A Review of the Effects of Dietary Fiber on Type 2 Diabetes

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Abstract: Type 2 diabetes (T2D) is a chronic disease with a high incidence worldwide, and its effective control has become a major public health concern. The urbanization phenomenon accompanying the rapid economic development, along with widespread sedentary lifestyles and high-calorie dietary patterns, have led to a sharp increase in the affected population, especially among those under the age of 40. In recent years, dietary fiber has received extensive attention due to its potential role in regulating blood sugar, improving insulin sensitivity and intestinal health. This review aims to summarize recent advances in research on the impact of dietary fiber on T2D, with a focus on its classification, intake levels, mechanism of action and intervention effects. Existing evidence suggests that dietary fiber has therapeutic benefits for T2D, including improvements in blood glucose and insulin levels, as well as a reduced risk of disease onset. However, at present, there are still problems such as poor population compliance and high heterogeneity in intervention studies. Therefore, more high-quality research needs to be carried out in the future to clarify the optimal intervention model of dietary fiber in diabetes management.

Keywords: Blood glucose, Dietary fiber, Type 2 diabetes.

1. Introduction

T2D is an increasingly common chronic non-communicable disease, accompanied by multiple complications [1]. As of 2021, approximately 536.6 million adults (aged 20 to 79) worldwide suffered from diabetes, among which T2D accounted for 90% of global diabetes cases, and the number of affected people is still growing rapidly [2]. It is predicted that by 2045, the number of T2D deaths in all age groups will continue to increase to 12.967 million [3]. This also imposes a huge burden on global public health. It is estimated that the cost for treating diabetes patients will reach approximately 1,054 billion US dollars by 2045 [1]. Therefore, effective mitigation measures must be found to reduce the incidence and prevalence of T2D. The current treatment status is mainly based on metformin. Since its first clinical use for hypoglycemic treatment in 1957, metformin has been widely recognized as a first line drug for the treatment of T2D and is often used in combination with lifestyle interventions [4]. This drug mainly exerts its hypoglycemic effect by acting on multiple cellular signaling pathways such as the intestine, liver and skeletal muscle. However, before using metformin, relevant contraindications must be excluded, especially renal function should be evaluated to ensure the safety of medication. If the condition worsens, such as the continuous deterioration of β cell function, the patient needs to start insulin treatment. Furthermore,

existing studies have shown that dietary intervention is regarded as one of the fundamental measures for controlling blood sugar levels, and it is also the most effective and safest approach. With the continuous progress of research, the role of dietary fiber in T2D has gradually attracted attention and importance. Dietary fiber is the carbohydrate in plant-based foods. Whole grains, bran, vegetables, fruits and legumes are the main sources of dietary fiber, which can provide the human body with a variety of fibers. For millions of years, it has always dominated the human diet structure.

Some studies have confirmed that the intake of dietary fiber is negatively correlated with T2D. Reasonable intake of dietary fiber can significantly improve insulin resistance, lower blood sugar levels, regulate blood lipids, and help control weight and inflammatory responses. It can be seen from this that dietary fiber can act on glycolipid metabolism through multiple mechanisms, thus becoming a simple and effective nutritional intervention method in the prevention and control of T2D. This article will systematically sort out and analyze the intake of dietary fiber and T2D, aiming to lay the foundation for the treatment of diabetes and provide a theoretical reference basis.

2. T2D

T2D is a heterogeneous disease and can lead to the occurrence of various complications, such as blindness, stroke, increased susceptibility to infection, renal failure. Diagnosis is usually based on indicators such as fasting blood glucose (FBG) levels exceeding 7.0 mmol/L or glycated hemoglobin (HbA1c) values higher than 6.5% [5]. Its characteristic is that insulin resistance and pancreatic β cell dysfunction lead to persistent hyperglycemia, and persistent hyperglycemia can trigger vascular lesions, which in turn cause damage to target organs. In the early stage of the disease, individuals usually show insulin resistance and hyperinsulinemia, that is, pancreatic β cells compensatorily secrete more insulin to maintain normal blood sugar levels. However, as the disease progresses, β cells gradually become exhausted, and their ability to secrete insulin declines. Eventually, insulin resistance cannot be overcome, resulting in persistent hyperglycemia.

In addition, an unhealthy lifestyle or metabolic syndrome can cause an increase in triglyceride (TG) and non-esterified fatty acid levels, leading to abnormal lipid deposition in non-adipose tissues such as the liver and skeletal muscle, blocking insulin signaling and thereby exacerbating insulin resistance. Meanwhile, an environment high in sugar and fat can lead to lipid deposition within β cells, damaging their secretory function and quantity, and exacerbating insulin deficiency. This state of coexistence of insulin resistance and β cell dysfunction constitutes the core pathophysiological mechanism of T2D. However, at different stages of the development of T2D, by intervening in lifestyle, especially increasing the intake of dietary fiber, the progression of the disease can be delayed to a certain extent. It is worth noting that there are numerous types of dietary fiber with different sources. Different types of dietary fibers vary in their physicochemical properties and metabolic pathways, and thus have significant differences in their effects on T2D control. Therefore, it is necessary to classify and discuss soluble and insoluble dietary fibers in order to have a more comprehensive understanding of their potential and control in diabetes intervention.

3. Overview of dietary fiber

The definition of dietary fiber is rather complex, involving both the nutritional aspect and the analytical concept. The most commonly adopted definition at present is mainly based on nutritional physiology, which holds that dietary fiber is the edible part of plant based or similar carbohydrates that is not easily digested and absorbed in the small intestine. The American Association of Grain Chemists defines dietary fiber as a carbohydrate polymer with a degree of polymerization exceeding

three degrees and is not digested and absorbed in the small intestine. Dietary fiber is mainly divided into soluble dietary fiber and insoluble dietary fiber. Soluble fiber, after entering the large intestine, is fermented by bacteria in the colon, generating active short-chain fatty acids (SCFAs) and helping to promote the growth of probiotics. Furthermore, this type of fiber can absorb water and form a gel in the intestines, thereby prolonging the retention time of food in the digestive tract. By delaying the emptying rate of the stomach, they can slow down the absorption of certain nutrients and make the entire digestive process smoother. In contrast, insoluble fibers such as hemicellulose, cellulose and lignin are hardly fermented in the digestive tract and can pass through the gastrointestinal system completely. Their main function is to promote intestinal peristalsis, shorten the time of defecation and increase the volume of feces, thereby helping to relieve and prevent constipation [6]. The global average intake of dietary fiber is approximately 15 to 26 grams per day, which is lower than the World Health Organization's recommendation of at least 25 grams per day [7]. Existing research results have shown that dietary fiber has been proven to lower the risk of T2D, whether by controlling blood sugar or reducing energy intake.

4. The control effect of soluble dietary fiber on T2D

It has been confirmed in existing studies that soluble dietary fiber can lower blood sugar in T2D. In terms of empirical research, a randomized controlled study explored the specific effect of soluble dietary fiber on blood glucose control in patients with T2D. A total of 120 middle-aged and elderly diabetic patients were included in this study, with 40 subjects in each group. They were divided into the control group (only receiving conventional dietary treatment, and 3 people withdrew due to personal reasons), the low-dose group (supplemented with 10 grams of soluble dietary fiber daily), and the high-dose group (supplemented with 20 grams of soluble dietary fiber daily). The intervention lasted for one month. The research results showed that the FBG level in the high-dose soluble dietary fiber group decreased from 8.71 ± 2.91 mmol/L to 6.13 ± 1.18 mmol/L, and the 2-hour postprandial blood glucose decreased from 12.54 ± 3.88 mmol/L to 8.08 ± 2.77 mmol/L. The insulin resistance index (HOMA-IR) also decreased significantly from 3.92 ± 2.77 to 2.12 ± 1.29 . Both FBG and 2-hour postprandial blood glucose levels decreased significantly, and HOMA-IR improved significantly. In contrast, the low-dose group also showed a certain degree of decrease in FBG and HOMA-IR. The FBG decreased from 8.26 ± 2.84 mmol/L to 7.26 ± 2.94 mmol/L, and the two-hour postprandial blood glucose decreased from 12.50 ± 4.20 mmol/L to 9.73 ± 3.81 mmol/L. HOMA-IR decreased from 3.40 ± 2.59 to 2.30 ± 1.58 , but the improvement amplitude was significantly smaller than that of the high-dose group. This also indicates that 20 grams of soluble dietary fiber supplements per day are more effective than 10 grams [8]. Researchers believe that this may be related to mechanisms such as soluble fiber forming gels in the intestine, slowing down the absorption rate of carbohydrates, promoting the production of SCFAs, and improving the intestinal flora. This research result provides a solid scientific basis for the application of soluble dietary fiber in the nutritional treatment of diabetes.

Systematic reviews and meta-analyses also provided higher-level evidence for the positive effect of soluble dietary fiber on blood glucose control in T2D. A meta-analysis selected 33 comparison groups from 29 randomized controlled trials, involving 1,517 patients with T2D. The research results show that compared with the control group, supplementing soluble dietary fiber can significantly improve the blood glucose control status, manifested as an average reduction of 0.89 mmol/L in FBG, an average reduction of 0.63% in HbA1c, and a standardized mean difference of -0.48 in fasting insulin, indicating that the fasting insulin level in the control group is lower than that in the control group. The standardized mean difference of HOMA-IR was -0.58, indicating that

HOMA-IR was lower and could effectively improve insulin resistance [9]. Natural foods have a significant effect on improving blood glucose control and insulin sensitivity in patients with T2D, and their hypoglycemic effect is affected by fiber type, intake dose and intervention duration. However, as most of the existing studies are short-term interventions and have high heterogeneity. More long-term and well-designed randomized controlled trials are still needed to further confirm this therapeutic effect.

5. The control effect of insoluble dietary fiber on T2D

Insoluble dietary fiber is not as effective in controlling T2D as soluble dietary fiber, but it can also help control blood sugar. An experimental research paper found that insoluble dietary fiber in kiwifruit exhibited anti-diabetic effects in a high-fat diet and streptozotocin induced T2D rat model. After 4 weeks of intervention, insoluble dietary fiber reduced FBG (from 27.25 ± 4.23 mmol/L to 24.32 ± 4.08 mmol/L) and HOMA-IR (from 48.29 ± 9.66 to 39.63 ± 8.28), and effectively improved blood lipid levels. For example, TG and total cholesterol decreased from 1.81 ± 0.16 and 5.64 ± 0.8 mmol/L to 1.12 ± 0.43 and 4.59 ± 0.52 mmol/L respectively [10]. Meanwhile, insoluble dietary fiber can significantly reduce the levels of inflammatory factors tumor necrosis factor- α and interleukin-6, and decrease the concentration of serum endotoxin Lipopolysaccharide, indicating that it has a positive effect in inhibiting systemic inflammation.

In addition, insoluble dietary fiber regulates the intestinal microecological balance and increases the abundance of beneficial bacterial communities such as Ruminococcaceae and Lachnospiraceae. It also increased the content of SCFAs, especially isobutyric acid (0.08 ± 0.01 μ g/mg vs model group 0.06 ± 0.01 μ g/mg). These changes were negatively correlated with blood glucose, lipids and inflammatory indicators, suggesting that SCFAs play a mediating role in metabolic improvement [10]. Insoluble dietary fiber also enhances the secretion of satiety hormones peptide YY and glucagon-like peptide 1, reduces food intake and inhibits weight gain. In conclusion, insoluble dietary fiber exerts a comprehensive regulatory intervention effect on T2D by regulating the intestinal flora and its metabolites, improving metabolic indicators and inflammatory states.

6. Discussion

This review systematically sorts out the potential role of dietary fiber in the control of T2D, emphasizing its benefits in lowering blood sugar, improving insulin sensitivity, regulating blood lipids and inhibiting inflammation. According to the existing research evidence, although soluble dietary fiber and insoluble dietary fiber differ in their mechanisms of action, both have shown positive intervention effects on T2D.

The research results show that soluble dietary fiber effectively regulates blood sugar levels and insulin resistance by forming gel-like substances, thereby delaying gastric emptying, reducing the absorption rate of carbohydrates, and promoting the production of SCFAs at the same time. These mechanisms have been verified in multiple clinical trials and systematic reviews, and high-dose intake (such as 20 grams per day) is more significant than low-dose intake. However, although short-term intervention studies have achieved positive results, the intervention time of current studies is generally short, the sample size is small, and the research heterogeneity is large. Therefore, further exploration is still needed for long-term safety and sustained efficacy.

In contrast, the effect of insoluble dietary fiber in blood sugar control is relatively limited, but it still plays an indispensable role in regulating the intestinal flora, anti-inflammation, and improving lipid metabolism. For instance, animal experiments on insoluble fiber in kiwifruit have shown that it

can significantly reduce inflammatory factors, increase SCFAs levels and regulate the secretion of metabolic hormones. This indicates that although insoluble dietary fiber does not directly act on the process of blood glucose absorption, it can have a positive impact on the overall metabolic state by regulating some parts, and has the intervention characteristics of multiple targets.

This review also points out some important issues existing in the current research. First of all, although soluble dietary fiber has a good effect in lowering blood sugar, its intake is generally insufficient in the actual dietary composition. Therefore, in future public health interventions, in addition to clinical nutrition guidance, it is also necessary to start from food structure adjustment and nutrition education to improve the acceptance and accessibility of high-fiber foods among the population. Secondly, there is still a lack of in-depth exploration on the adaptability and individualized responses of dietary fiber in different populations. For example, differences in age, gender, composition of intestinal flora and metabolic status may affect the intervention effect. Therefore, individualized nutritional intervention will be an important direction for future research.

In conclusion, dietary fiber, as an economical, safe and effective nutritional intervention method, has broad application prospects in the comprehensive management of T2D. In the future, it is necessary to further promote the accumulation of high-quality evidence and facilitate its standardized application in clinical practice and public health strategies.

7. Conclusion

This review summarizes the multi-faceted roles of dietary fiber in the control of T2D. Dietary fiber can effectively assist in the management of diabetes through mechanisms such as improving blood sugar levels, enhancing insulin sensitivity, regulating intestinal flora and inhibiting chronic inflammation. Although current evidence supports the positive impact of dietary fiber on T2D, more high-quality, long-term follow-up studies are still needed to clarify the optimal intake, fiber type and applicable population. Public awareness of the benefits of dietary fiber should also be enhanced, and its inclusion in the comprehensive intervention strategy for diabetes should be promoted to improve the diet quality of the population and the level of chronic disease prevention and control.

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