Effects of Soluble and Insoluble Dietary Fiber on Gut Microbiota and Metabolic Function in Patients with Metabolic Syndrome

Ruiling Wang
Health College of Medicine, Dezhou College, Dezhou, Shandong, China

Abstract: The regulation of dietary fiber (DF) on gut microbiota plays an important role in the occurrence and development of metabolic syndrome (MetS). However, there are few studies on the mechanism of soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) on gut microbiota. Through systematic review and integration of recent studies, this paper reveals that SDF regulates glucose and lipid metabolism mainly through rapid fermentation-metabolite signaling pathway. While IDF changes the structure of intestinal flora through physical structure-slow-release fermentation. The two complement each other and act together on the prevention and treatment of MetS. Therefore, this paper proposes that the recommendation of DF intake should be changed from simply increasing a certain type of DF to increasing the ratio of SDF and IDF, and then to individualized intake for different individuals. This can provide theoretical basis and practical guidance for the dietary prevention and treatment of MetS.

Keywords: **Metabolic Syndrome; Gut Microbiota; Soluble Dietary Fiber; Insoluble Dietary Fiber**

1. Introduction

Because the incidence of MetS is increasing year by year, many scholars have conducted relevant studies on the effect of DF on MetS. DF can improve intestinal flora and reduce the risk of cardiovascular disease and type 2 diabetes. However, few scholars have compared the similarities and differences of the effects of SDF and IDF on intestinal flora and metabolites. Therefore, this article mainly reviews the related studies on the effects of SDF and IDF on intestinal flora and metabolites by reviewing the literature, and compares the differences between the two. The differential regulatory mechanisms of the two are compared from the dimensions of physical and chemical properties, flora composition, metabolic pathways, and so on, and finally puts forward corresponding dietary recommendations. It is hoped that this will help people to further understand the difference in the mechanism of action of DF on MetS patients, and provide a reference for MetS patients to choose DF in their daily life.

2. Consensus and Disagreement on the Effects of Dietary Fiber on Gut Microbiota and Metabolism

It has been widely recognized that DF has multiple positive effects on gut microbiota and its metabolic function. DF can be used by intestinal microorganisms to produce some beneficial substances in the host body, such as short-chain fatty acids (SCFAs). These products can provide energy for colonic epithelial cells, strengthen intestinal barrier, reduce inflammatory response, and regulate energy and glucose and lipid metabolism. [1,2]In recent years, many clinical studies, cohort studies and meta-analyses have shown that a diet high in dietary fiber can improve the structure of intestinal flora, increase the number of beneficial bacteria in the gut, and improve the metabolic environment, which is conducive to improving human health. [3]Therefore, it is an effective and feasible method to improve intestinal and metabolic health by suppleming DF, regulating intestinal flora and improving metabolic protective factors.

Although the health benefits of DF are generally recognized, its specific application is still controversial. The core is that there are significant differences in the effects of DF on individuals, mainly due to the unique composition of the baseline gut microbiota of the subjects. One study found that DF intake may have different effects on people with different microbiota composition, suggesting that a "one-size-fits-all" intervention model is not advisable. [4]Recent systematic analyses have shown that increasing fiber intake can improve blood glucose in a number of randomized

controlled trials, but the changes in gut microbiota across studies are inconsistent, so gut microbiota cannot be considered to be the only factor affecting its effect. [5]In addition, some studies have mentioned that in addition to SCFAs, DF also has an effect on other metabolites such as secondary bile acids and amino acid derivatives, so other factors cannot be excluded. [6]Therefore, the current role of DF on health is no longer limited to whether it is beneficial, but more attention is paid to the effect of its action in different populations.

3. Differential Effects of Two Types of Dietary Fiber on Gut Microbiota and Metabolism

3.1 Physicochemical Properties of Two Types of Dietary Fiber

DF can be divided into SDF and IDF according to their solubility. The different physicochemical properties of the two kinds of DF are the basis of their differential effects in patients with metabolic syndrome. SDF (such as inulin, pectin, and β-glucan) are easily soluble in water and can form gel-like viscous solutions, which can increase the viscosity of digesta and slow down gastric emptying and absorption of nutrients. IDF (such as cellulose and lignin) can not dissolve in water, but has a loose porous fibrous structure, which can promote intestinal motility by increasing the volume of feces and stimulating intestinal peristalsis. Therefore, for MetS patients with slow intestinal peristalsis, IDF with this property can help them to defecate smoothly. However, recent studies have suggested that the function of fibers is not only related to the physical morphology of fibers, but also to water holding capacity, water swelling, particle size distribution, and surface structure. [7]For example, plant-derived dietary fiber (PDF) can improve PDF solubility, porosity, and functional group exposure through key modification techniques, which may affect the intestinal flora of patients with MetS. [8]Therefore, it is advocated to go beyond the simple binary classification of "soluble and insoluble" and to classify substances according to fine physical and chemical properties such as molecular size, particle size, local concentration, and fermentation speed. [9]Therefore, DF with different physical and chemical properties have different effects on improving intestinal flora and metabolism in patients with MetS.

3.2 Differential Effects of Two Types of Dietary Fiber on Gut Microbiota in Mets Patients

The effect of DF on intestinal flora is also an important way to improve patients with MS. Different types of DF have different effects on intestinal flora due to different characteristics such as solubility, viscosity and fermentability. Therefore, different types of DF can be used to adjust intestinal flora to achieve the purpose of treating MetS.

The regulation of SDF is highly specific and metabolic efficient. Studies have shown that can selectively promote some bacteria of the genus proliferation, for example, found that apple pectin promoted intestinal china-arab g mann's bacteria (Akkermansia) and huge spherical bacteria belong to the growth of (Megasphaera), and Mr Ackman's bacteria abundance lower is a common manifestation of the metabolic syndrome. [10]In addition, the SDF has higher efficiency of fermentation, can produce a large number of SCFAs, its metabolites can be used as the host of energy source, but also can be adjusted to local and systemic inflammatory response. [11]In contrast, IDF plays its role by changing the composition of intestinal flora and improving the structure of intestinal flora. For patients with MetS, IDF supplementation can increase the flora related to the complex fermentation of carbohydrates. Studies have found that higher IDF intake is positively correlated with microbial community structure. In addition, long-term intake of IDF improves the α-diversity of intestinal flora. [12]Therefore, different microbiota structures produce different metabolites, leading to different effects in MetS patients.

3.3 Differential Effects of Two Types of Dietary Fiber on Key Metabolic Pathways

The differential effects of SDF and IDF on metabolic function in patients with MetS are fundamentally due to the different regulation modes of metabolic pathways. SDF mainly improves glucose and lipid metabolism through rapid fermentation products, while IDF mainly regulates the stability of body metabolism through physical effects and slow-release fermentation.

The regulatory effects of SDF are direct and structurally specific. SDF directly acts on intestinal flora and is broken down into SCFAs under the action of intestinal flora, which can

stimulate the corresponding G protein-coupled receptors on intestinal epithelial cells and immune cells to release incretins such as glucagon-like peptide-1 (GLP-1), thereby regulating insulin and energy balance. [11,13]Secondly, due to the different chemical composition of SDF, the effects of SDF on microorganisms are different. In a multi-omics study in overweight individuals, arabinoxylan oligosaccharides (AXOS) were found to selectively increase the abundance of Prevotella, increase the content of multiple butyric acids, and reduce the content of ceramide in plasma, improving the metabolic status. [14]Studies have confirmed that the chemical structure of SDF can promote the differential metabolic remodeling of intestinal flora, thereby achieving the precise regulation of host glucose and lipid metabolism. [15]In contrast, the effect of IDF on microorganisms is indirect and slow. It is not quickly degraded, but regulates by physical adsorption and increasing the volume of feces. In addition, physical, chemical or biological methods can be used to change its structure and increase its fermentation rate, thereby improving the intestinal flora. [16]More importantly, since phenolic compounds can combine with IDF to form new compounds, these compounds can not only change the composition and increase the production of SCFAs, but also act as phenolic metabolites to exert anti-inflammatory and anti-oxidative effects locally, and eventually indirectly affect other organ systems by improving the intestinal environment and enhancing the body's immunity. It can achieve the purpose of preventing and treating metabolic diseases. [17]IDF can affect other metabolic pathways by regulating intestinal flora, which is complementary to the direct regulation of SDF.

SDF and IDF synergistically correct glucose and lipid metabolism disorders in patients with MetS through direct and indirect ways, respectively. Therefore, understanding this fundamental difference is conducive to the realization of personalized dietary intervention for MetS patients.

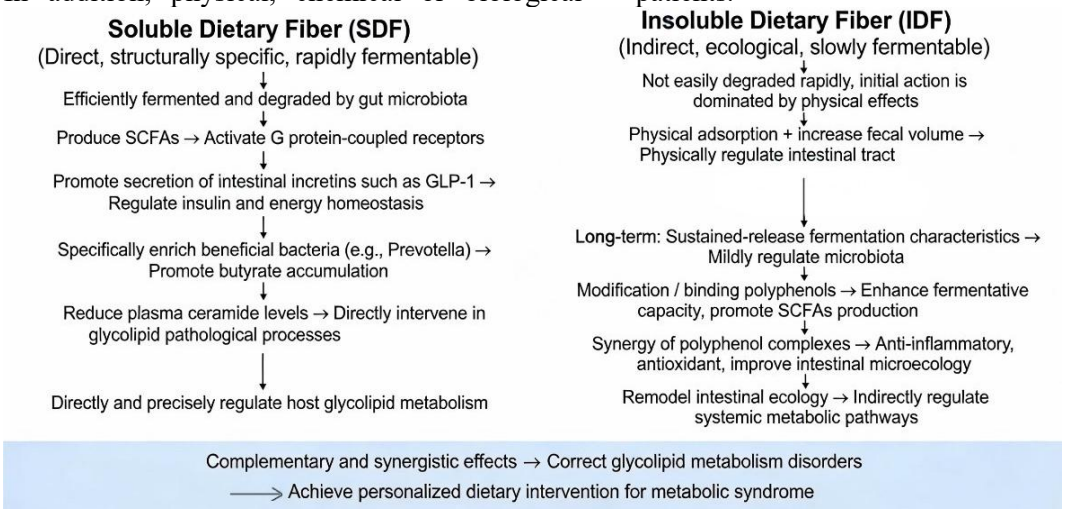

Figure 1. Schematic of the Mechanism of Differential Regulation of Metabolic Syndrome by SDF and IDF1

4. Recommendations for Dietary Intervention

4.1 Applicable Scenarios for Single Dietary Fiber

For patients with MetS, giving priority to a single type of DF can achieve precise intervention. When postprandial blood glucose and insulin response are the main targets for adjustment, SDF can be taken more. A study in overweight/obese individuals demonstrated that 25g of pea fiber per day decreased the area under the curve for postprandial glucose after 4 weeks. [18]The key point is that SDF can alter glucose metabolism due to its hyperlytic nature. In addition, a systematic review indicated that resistant starch was more effective than other soluble dietary fibers in improving postprandial insulin responses in overweight or obese individuals. [19]Therefore, such patients can appropriately consume more foods rich in SDF, such as oats, beans, citrus fruits, and foods high in resistant starch, to improve their symptoms. IDF is more valuable for people who need to control body weight, reduce blood lipids, or maintain intestinal stability. In a direct comparison, one study found that IDF supplementation was less effective than SDF in

the immediate effect on blood glucose, but SDF was more effective in regulating lipid metabolism and helping to improve the structure of the microbiome. [20]IDF can absorb water and expand, produce satiety, release slowly, and ferment continuously, which can ensure the diversity of intestinal microorganisms. While SDF acts quickly and cannot regulate intestinal microbes for a long time. Therefore, when choosing a better glucose control effect, we should also pay attention to the homeostatic effect of IDF on intestinal microorganisms.

4.2 Combined Intervention Strategy of Two Types of Dietary Fiber

Although the effect of single DF intervention on the improvement of MetS is relatively obvious, considering the interaction between different types of DF, the combined intervention of multiple DF may be more conducive to the improvement of MetS, and the key to combined intervention is scientific matching. An animal experiment showed that different ratios of SDF to IDF had different effects on intestinal flora and metabolic function. [20]This suggests that the ratio of SDF to IDF in DF should be adjusted according to the patient's own condition in clinical practice. However, it is the food itself, not the fiber itself, that is most important during intervention. A human study found that endogenous plant-cell fibers that contain plant cell walls may be more effective than refined fibers in increasing gut microbial diversity and thereby improving insulin resistance in obese people. [21]So eat whole grains, legumes, and a lot of fruits and vegetables is a better choice, because these foods contain two kinds of DF, and can ensure that fiber and other plant nutrients work together, help to the improvement of the MetS.

4.3 Individualized Intervention of Dietary Fiber

Since different patients have different responses to DF, the success rate of DF intervention can be improved by developing individualized DF intervention programs. A randomized controlled trial mentioned that for subjects on a high-protein diet, additionalsupplementation of slow-fermented fiber mixture had no benefit or even harm to insulin sensitivity,[22] showing the impact of being out of touch with the realistic dietary environment on the results. In addition, another study found that people with low whole grain intake and low dietary fiber intake had a better effect on lowering blood pressure after consuming prebiotics fiber. [23]In other words, patients' dietary status and gut microbiota before intervention may also be one of the factors affecting the effect of intervention. Therefore, in the future DF intervention for MetS patients, it is necessary to establish a dynamic path of "monitoring + adjustment" when increasing DF intake, so as to achieve personalized adaptation.

5. Conclusions

This review systematically reviewed the existing literature on the regulatory effects of SDF and IDF on patients with MetS. In general, the existing evidence shows that SDF and IDF synergistically improve the metabolic state of MetS through two complementary pathways, which provides a theoretical basis for clinical dietary intervention. SDF is mainly rapidly fermented through chemical pathways to produce beneficial metabolites with SCFAs as the core, which directly acts on the human body environment and regulates the related metabolic pathways in the human body, so that blood glucose and insulin can be improved in a short time. IDF can increase the volume of feces, slowly ferment intestinal microorganisms, regulate the diversity and richness of intestinal microorganisms, and indirectly affect the human body environment for a long time. However, it should be noted that different individuals have different responses to different types of dietary fiber, different baseline flora, and different dietary scenarios, and the results of DF intervention will also be different, indicating that the "one-size-fits-all" intervention program is changing to individualization. This study is mainly based on the integrated analysis of the existing relevant literature, which is derived from the induction of independent studies. There is no unified experimental method and model for comparison, and the effect difference of the two DF interventions cannot be directly drawn from this article. In addition, most of the individualized intervention studies on individuals are simple descriptions of the mechanism and intervention effect, and no guidance plan for different individuals has been formed. In conclusion, based on the current limitations, how to make full use of the differences between SDF and IDF and carry out precise nutritional intervention for different individuals to achieve the goal of prevention and

treatment of MetS needs further exploration in the future.

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