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Dietary structure and pattern in prevention of prediabetes

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Abstract. The light manual labor work pattern of modern society has led to difficulties in blood sugar management, rising obesity rates, and an increase in the number of diabetes patients. Prediabetes is a condition where blood glucose levels are elevated but not high enough for a diabetes diagnosis. Prediabetes represents a critical stage for the development of type 2 diabetes (T2D), with symptoms including abnormal fasting blood glucose (IFG), impaired glucose tolerance (IGT), and glycated hemoglobin (HbA1c) concentrations. This review explores the diagnostic criteria for prediabetes and dietary management approach of preventing the state of prediabetes. Poor diet and inadequate physical inactivity are key contributors to the rise in prediabetes cases. Dietary interventions such as understanding your diet structure, following health dietary patterns are effective strategies for managing blood glucose level and preventing prediabetes. The Mediterranean diet, DASH diet, and plant-based dietary patterns have protective effects in reducing T2D risk by promoting insulin sensitivity and reducing inflammation. Overall, it is important to combine dietary and lifestyle approaches to prevent prediabetes.

Keywords: Prediabetes, carbohydrates, protein, fat, fiber, dietary pattern.

1. Introduction

Prediabetes is a condition where blood sugar levels are exceeding the normal range but not yet high enough to be diagnosed as diabetes. It represents a transitional phase of abnormal blood sugar levels between normal glycemia and full-blown diabetes [1]. The word “prediabetes” is not a perfect word to describe this state on an individual since the transition to a fully developed diabetes is not necessarily. In fact, the World Health Organization use “intermediate hyperglycemia” and another professional organization, the American Diabetes Association uses the term “high-risk state of developing diabetes” to describe prediabetes. Prediabetes refers to the statements of impaired fasting glycemia (IFG), impaired glucose tolerance (IGT), and abnormal HbA1c concentrations in this article. In clinical practices, prediabetes is usually diagnosed by the test measuring fasting blood glucose (FBG), glycosylated hemoglobin (HbA1C), or 2-h post-load blood glucose (2hBG) [1]. However, different criteria are used to diagnose prediabetes. Those criteria are not fully consistent with each other and bring challenges to the collection of statistics on the population with prediabetes. Even though there’s no comprehensive global prevalence data on prediabetes, the prevalence of diabetes is increasing, and it gives a great challenge to global health.

There are 3 major types of diabetes, type 1 diabetes, type 2 diabetes and pregnancy-induced diabetes. More specifically, prediabetes mostly leads to type 2 diabetes. Type 2 diabetes is a common metabolic disorder, caused by insufficient insulin secretion of β cells in pancreas or insulin resistance. Insulin is

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an endocrine hormone; it helps with the assimilation of glucose in the human body and maintains blood glucose balance [2]. Many factors would cause insulin resistance for example stress, diet and obesity [3]. Insulin resistance interferes with cellular response of insulin thus decreasing the tissue glucose uptake and finally disturbing blood glucose level [2].

According to the world health organization, 8.5% of adults aged 18 and older had diabetes in 2014 [4]. By 2019, diabetes directly caused 1.5 million deaths, with 48% of these occurring before the age of 70 [4]. Additionally, diabetes was responsible for 460,000 deaths from kidney disease and contributed to approximately 20% of deaths related to cardiovascular issues. Diabetes also brings heavy financial burden to individuals [4].

From a broad perspective, the work pattern of modern society is dominated by light manual labor, people tend to have less physical activities, fast foods, takeout foods Significantly increased [5]. Fast food has low nutrient density, high in calories, large portions, and contains significant amounts of processed meat, refined carbohydrates, sugary drinks, and unhealthy fats. This has led to difficulties in blood sugar management, an increase in obesity rates, and a rise in the number of people with diabetes. Diet management has been proved as an effective way to control blood sugar level and improve the high-risk state of development of diabetes in the past decade [5]. Besides control blood glucose level by diet management and increasing physical activity time, patients could also use medicines to help manage blood glucose. Comparing with medicine use, diet management has fewer or even no side effects, a good diet management has a universal health benefit for example lower the risk of having cardiovascular disease, hypertension or chronic diseases like obesity. Diet management has many long-term benefits and additionally, it is more cost-effective compared with other treatments.

2. Carbohydrates

Carbohydrate is the main source of calories for the human body, and it takes a large portion in a typical diet. Fiber, starches and sugars are 3 major kinds of carbohydrate. It is widely agreed that both the quality and quantity of carbohydrates are key factors in predicting glycemic response [6]. For prediabetes individuals, they should lower the ratio of carbohydrates in their meals and choose high quality carbohydrates.

2.1. Glycemic index and glycemic load

Dietary patterns with a low glycemic index (GI) and/or low glycemic load (GL) have been proven to promote glycemic control [6].

GI is an index to estimate the digestion and absorption of carbohydrate-containing foods and the speed of increasing blood sugar. The higher the GI value, the faster the blood sugar rises and the insulin response due to the fast digestion and absorption. On the contrary, the lower the GI value, the slower the response. GL introduces the evaluation of the total carbon content in food while considering the absorption speed. GI and GL are both important indicators that need to be referred to in the process of controlling blood sugar. According to a study from the United States, the risk of T2D is positively correlated with the GI value of food [7]. Therefore, it is necessary to choose low GI foods in the diet.

2.2. Grains or refined grains

Replacing refined grains or refined grain products with whole grains can help control blood sugar and prevent the occurrence of diabetes. Wholegrain is the grain with all the endosperm, germ and bran, meanwhile, refined grains only contain the endosperm [8]. A large number of experimental studies have shown that consuming whole grains can reduce the incidence of various diseases, including type 2 diabetes.

2.3. Beans and legumes

Beans and legumes are also ideal options to place in the diet to help with glycemic control. One research from Spain has found that the risk for developing a type 2 diabetes is reduced almost 50% when

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substituting refined grain products with legumes in their meals [9]. Popular food examples are lentils, green peas, chickpeas and soybeans.

2.4. Dietary fiber

Among the various dietary components, dietary fiber has garnered substantial attention for its potential role in mitigating the risk of developing T2D. From a meta-analysis by Weickert and Pfeiffer in 2018, it found that women who consume more than 25g of dietary fiber per day and men who consume more than 38g of dietary fiber per day may reduce their risk of type 2 diabetes by 20%-30% [10].

Among them, soluble fiber can reduce the absorption rate of starchy foods, thereby reducing the rate of blood sugar increase. Rapidly digestible starch (RDS) in food could be reduced when people have more soluble fiber in diet, soluble fiber could also increase the portion of resistance fiber (RS). RDS refers to those starch parts that can be quickly broken down into glucose by enzymes during digestion, causing blood sugar levels to rise rapidly and RS refers to those starch parts that not able to be broken down by intestine enzymes, so they are not digested and absorbed, or are digested and absorbed very slowly. Secondly, soluble fiber could increase the intestinal content viscosity, thereby slowing gastric emptying and the breakdown of starch granules, delaying the exposure of starch to digestive enzymes. Also, SDF has superior hydration and swelling properties, SDF-enriched foods take up more space in the stomach compared to control foods [11]. As a result, SDF-enriched foods promote greater feelings of fullness, leading to a reduction in the amount of food or energy consumed in later meals.

Surprisingly, some soluble fiber could be a kind of amylase inhibitor, as we mentioned ahead, soluble fiber would increase the viscosity of intestinal contents thus decrease the chance for intestinal contents react with amylase. Additionally, some soluble fibers have been found to possess the ability to bind or form complexes with amylolytic enzymes, prevents starch molecules from accessing the active sites of these enzymes [11].

Again, intestinal fermentation of soluble fiber can produce short chain fatty acid (SCFA). SCFA is very helpful for blood sugar control and insulin sensitivity. Many studies indicate that the risk of developing diabetes could be reduced significantly by increasing the consumption of dietary fiber in the meals. Increasing the fiber amount in the diet can improve the body's blood sugar control and increase insulin sensitivity. The gut microbiota has been demonstrated to affect human health through various physiological processes. Soluble fibers as prebiotics can be selectively processed by certain intestinal bacteria, among these compounds produced by the bacteria, short-chain fatty acids (SCFAs) are the most interesting ones since they participate in different intestinal activity regulations [12].

3. Dietary proteins

Protein plays a key role in glucose homeostasis as a necessary macronutrient. The dietary protein intake, protein quality, and the risk in prediabetes has been a subject of research. Current evidence suggests that blood glucose control and insulin sensitivity is affected by both the quantity and source of protein in our diet.

3.1. Red Meat and processed meat

Red meat, particularly processed varieties, has been found to have a stronger effect of developing T2D. According to a review by Kim et al., which analyzed findings from four different meta-analyses, the development of type 2 diabetes is positively correlated with consumption of red meat and especially processed ones [13]. Red or processed meat can induce risk factors of type 2 diabetes, insulin resistance and inflammation by different pathways.

For example, red meat contains a high amount of heme iron, which could be easily absorbed by human body, iron can interfere with insulin binding by causing oxidative stress in cells and it plays a key role in producing reactive oxygen species then causing damage to pancreas β-cells function [13].

On the other hand, nitrites and nitrates in processed meat would react with amino group in stomach to form nitrosamine. Studies have found nitrosamine could cause insulin resistance and damaging β-cells in pancreas [14].

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3.2. Dairy Products

The main protein source for milk and dairy products is casein and whey protein, although not enough research finds potential relationship between casein or whey protein and the risk of developing T2D, dairy products do have a complex relationship with T2D risk. Study have demonstrated that milk would trigger a stronger insulin response than glucose in a shorter time period, it also finds that for individuals whose glucose sensing and signaling is defected, their beta cells may still keep the sensitivity towards certain protein or nutrient combinations in dairy products. This can be explained by other nutrients in milk for example the calcium, magnesium and vitamin D [15].

3.3. Plant Protein

Plant proteins, such as those from legumes, nuts, and whole grains, are decent sources to substitute with animal proteins. These proteins are rich in fiber and have a favorable amino acid profile, which may contribute to improved insulin sensitivity. As mentioned before, the fiber and vitamins in those plant-based food would do a lot to help control blood glucose level and help with insulin sensitivity [11]. Additionally, plant proteins do not contain heme iron and are typically lower in saturated fats, which may further contribute to their protective effect against T2D.

3.4. Branched-Chain Amino Acids (BCAAs)

BCAAs, including valine, isoleucine and leucine, have been a subject of interest in the context of T2D. While they can promote muscle protein synthesis, which is a necessary section of the secretion of insulin, excessive intake of BCAAs, particularly from animal sources, seems to be linked to insulin resistance [16]. BCAAs active the target of mTOR pathway, it is a special protein kinase that controls cellular protein synthesis. In this case, moderate intake of BCAA source food would increase insulin production, however when the amount of BCAA exceeds certain range, the chronic mTOR pathway activation may lead to insulin resistance [17].

3.5. Limitations of High-Protein Diets

High-Protein diet can help in short term weight loss and glycemic control, however, the long-term effect on management of diabetes is less clear. High-protein diet could increase kidney workload, especially for people with renal impairment. Additionally, if protein source is mainly from animal source or only from a certain kind of food, it may lead to an imbalanced nutrient intake status.

Protein quantity or quality is closely linked to glucose metabolism and the development of diabetes. High-quality proteins from a plant-base diet or lean animal protein can support glycemic control while excessive amount of red meat and processed meat may increase the risk of diabetes. As discussed, insulin sensitivity and glucose hemostasis could be used to explain the possible metabolism mechanism

In conclusion, the type and quantity of dietary protein intake are both linked to glucose metabolism and T2D risk. High-quality proteins from plant sources and lean animal products can support glycemic control, on contract, the risk of T2D may increase because of excessive amount of processed meats or red meat. The complex interactions between dietary components and metabolic pathways could influence insulin sensitivity and glucose homeostasis. More research is needed to clarify the long-term effects of various protein sources on T2D risk in the future.

4. Dietary fats

Dietary fats are a key component in human nutrition, it is the source of energy and also have their influence on glucose metabolism. Both the quality and quantity of fat consumed can influence the risk of prediabetes.

Unsaturated fats, including monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA), have been found beneficial effects and impact on blood glucose control.

One systematic review by Schwab et al. (2014) evaluated the risk of T2D and quality and quantity of dietary fat. This review article collected multiple randomized controlled trials and found out that the risk of developing T2D is reduced since the improvement of insulin sensitivity. Replacing saturated fat

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with MUFA or PUFA also lowers LDL cholesterol levels, improving lipid profile and indirectly affect insulin sensitivity according to their research [18].

The quantity of dietary fat also matters. Diets high in saturated fat can cause obesity, which is a risk factor for diabetes. Meanwhile, appropriate fat amount is a key characteristic of a healthy diet for example the Mediterranean diet [19].

In conclusion, glycemic control is adjusted by the quality and quantity of dietary fat. Replacing saturated fat with health fat sources olive oil, fish oil or different food that rich in MUFA or PUFA, maintaining a balanced diet with appropriate physical activity is very important in managing the risk of developing prediabetes.

5. Dietary patterns

Managing the risk of developing prediabetes through dietary approach is ideal for most people. Choosing a healthy diet model is important and also more accessible. Classic health diet models such as Dietary Approaches to Stop Hypertension (DASH) diet, the Mediterranean diet, plant-based diets, and other dietary patterns, have shown potential in preventing and managing diabetes.

5.1. The Mediterranean diet

The Mediterranean diet (MedDiet) is rich in whole grains, fruits, olive oil, nuts, vegetables and consumption of fish and poultry. This diet model has been well studied for its health benefits, especially in terms of reducing the risk of and diabetes and cardiovascular diseases. The Mediterranean diet encourages high consumption of MUFA from olive oil and less intake of red or processed meats. As mentioned in previous section, the MUFA is associated with better management of risk factors for prediabetes for example insulin sensitivity, reduction in inflammation and oxidative stress [20].

Their research showed a great drop in the risk of T2D among participants following to this dietary pattern. Participants following a MedDiet who put more nuts or olive oil had a 40% reduced risk of developing T2D compared to those on a control diet [20]. The anti-inflammatory properties of the MedDiet, high fiber content, and positive impact on insulin sensitivity explains these beneficial effects. The polyphenols found in olive oil and other plant-based foods in this diet have positive effects on glucose metabolism and would help reduce the risk of insulin resistance, which is essential to the prevention of diabetes [21].

The research by Guasch-Ferré et al. discussed how the Mediterranean diet and dietary polyphenols in the diet could have the positive impact on preventing prediabetes. This review underlines how the polyphenols in the Mediterranean diet could help in preventing prediabetes. Possible biological mechanisms are uptake in cell, and the reduce of inflammation and oxidative stress, which are critical causing T2D and improved sensitivity of insulin [22].

One of the key findings in the review is the beneficial effect of the Mediterranean diet, specifically polyphenols, found in cocoa, chocolate, and red wine [22]. The review suggest that consumption of these food can lead to improve insulin resistance and other risk factors of prediabetes.

Finally, the review called the need for further research for more deep understandings in the metabolic effects of polyphenols and gut microbiome in metabolizing polyphenols and its impact on glucose homeostasis.

5.2. DASH Diet

the DASH diet is designed to manage blood pressure, but it also shown positive effects in managing and preventing diabetes. The DASH diet encourages the consumption of vegetables, fruits, whole grains, low-fat dairy, lean proteins, and reduced sodium [23]. Hashemi et al., evaluated` the DASH diet on patients with T2D and hypertension by their trial. Over 12 weeks, participants following the DASH diet experienced reductions in blood pressure. This phenomenon is critical to the prevention of diabetes since the close link between hypertension and diabetes complications [Hasemi]. Although the primary focus of the DASH diet is cardiovascular health, it contributes to improved insulin sensitivity and glycemic regulation due to its nutrient-dense, low-sodium and high fiber content feature.

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5.3. Plant-Based Diets

The research done by Qian et al. explored the association between plant-based diets and the risk of developing T2D. Their review analyzed data from nine prospective observational studies involving over 300,000 participants, finding that a reduction in the risk of prediabetes has appeared to those followed a plant-based diet. Plant-based diets limits or avoids animal products, focusing on foods such as fruits, whole grains, legumes, and nuts or other vegetables. The protective effects of plant-based diets were stronger when participants consumed mostly whole, unprocessed plant foods. On the other hand, diets that included refined grains, sugars, and processed plant-based foods associated less level of risk reduction [24].

As discussed in previous sections, plant-based diets with high quality carbohydrate sources for instance whole grains, rich fiber content, and low glycemic index foods significantly affect glycemic response by providing less unsaturated fat and positive effects on insulin sensitivity and reduction of inflammation. Also, following a plant-based diet would reduce red and processed meat intake, which means less chance to have saturated fat and nitrate content, further contributes to the beneficial impact of plant-based diets on diabetes prevention.

5.4. Other Dietary Patterns

Another systematic review by Papamichou et al. examined various dietary patterns and their effectiveness in managing T2D. The study emphasized that no one-size-fits-all approach exists, as individual responses to dietary changes can vary. However, the common thread across the most effective dietary patterns is the focus on whole, minimally processed foods rich in fiber, antioxidants, and healthy fats.

Low-carbohydrate diets, often recommended for diabetes management, were discussed in the review, focused on their short-term benefits for glycemic control [25]. However, long-term use of low-carb diet may bring challenges, since the balance of macronutrients is essential to avoid negative impacts on health. Conversely, the Mediterranean and plant-based diets are associated with sustainable, long-term benefits due to their balanced composition of fats, proteins, and carbohydrates.

The review also highlighted the role of intermittent fasting and time-restricted eating patterns in diabetes management. These approaches can support blood glucose management by limiting the window of eating [25].

5.5. Key Findings and Recommendations

The general theme from these studies is that dietary patterns rich in plant-based, whole foods, healthy fats, and fibers are most effective in preventing and managing T2D. The table 1 summarize the findings:

Table 1. Dietary patterns in preventing prediabetes.

Dietary Pattern	Key Benefits	Focus
Mediterranean Diet	Significantly reduces the risk of T2DM through anti-inflammatory properties and high fiber content.	Emphasizes healthy fats from olive oil and nuts, and includes high intake of fruits, vegetables.
DASH Diet	Effective in managing both blood pressure and diabetes risk, improves glycemic control.	Focuses food source such like fruits, vegetables, whole grains, and low-fat dairy products.
Plant-Based Diets	Reduced risk of T2D, supports insulin sensitivity and reduces inflammation.	High in whole, unprocessed plant foods, rich in fiber, antioxidants, and unsaturated fats.
Other Dietary Patterns	Offers short-term glycemic benefits, especially low-carb and intermittent fasting diets.	Requires more research for long-term effectiveness, with focus on carbohydrate restriction.

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The prevention of prediabetes through dietary intervention is a well-supported strategy. The Mediterranean, DASH, and plant-based diets give people benefits for preventing and managing T2D. In summary, those diets have common characteristics, for example focus on plant-based or healthy fat sources, having high quality carbohydrate sources, high fiber, low processed food content. Following a healthy diet would lower the risk of a prediabetes by improving insulin sensitivity. Additionally, public health units should focus on promoting these dietary patterns to reduce the global burden of diabetes.

6. Conclusion

This review article discussed the concept of prediabetes, dietary components and structures and their role in prevention of prediabetes. Prediabetes is a state when glycemic level is impaired but not reaching diagnostic criteria for diabetes. Prediabetes is associated with increasing risk of developing a diabetes, being aware of the state of prediabetes is critical to manage overall health status and taking actions

First, this article points out that being in the state of prediabetes is not necessarily related to the transition into any kind of diabetes, however it does increase the risk. The diagnosis of prediabetes could be various depends on different criteria. Common diagnosis including impaired fasting blood glucose, HbA1C and postprandial blood glucose. Those difference diagnosis do bring challenge to calculate the prevalence of diabetes, however the current situation is the prevalence of diabetes is rising and using appropriate prevention measures or treatment becoming more and more important.

In terms of diet structure, it is important to focus on the 3 major macronutrients, carbohydrates, proteins and fats. First, carbohydrates as the most direct factor in blood glucose level, should be put in prior consideration, focusing on having high-quality and fiber-rich source such like whole grain, beans and legumes. Fiber is another key section people should add in their diet since its benefits in slowing down carbohydrate absorption rate and supporting glycemic control.

The article also discusses the effects of protein and fat intake on blood sugar control. High-quality protein from plant sources and lean animal products, can support glycemic control. Excessive intake of processed or red meat may increase the risk of type 2 diabetes. Unsaturated fatty acids, especially monounsaturated and polyunsaturated fats, have a positive effect on glycemic control. However, high-fat diets that are rich in saturated fat, may lead to obesity, which is an important risk factor for prediabetes.

In terms of dietary management, this review discussed the application of various dietary patterns on the prevention and control of prediabetes. The Mediterranean diet, the DASH, and plant-based diets all show potential in preventing the development of type 2 diabetes. These dietary patterns emphasize the intake of whole grains, high-fiber and low-fat dairy products and limited intake of red or processed meat products.

More specifically, the Mediterranean diet focuses on high monounsaturated fatty acids food sources such as olive oil and polyunsaturated fatty acids, as well as its high fiber content. It has been shown to improve insulin sensitivity, reduce inflammation and oxidative stress thus reduce the risk of type 2 diabetes. The DASH diet has also shown benefits in managing blood pressure level and give an indirect effect to support blood sugar and reducing the risk of diabetes by focusing the intake of whole grains, fruits, vegetables, and low-fat dairy products. Plant-based diets encourage people have more plant-based food and avoiding animal products. The common features of these dietary patterns are high fiber, low processed food content, and a focus on plant-based or healthy fat sources.

Finally, the review concludes the importance of preventing diabetes through dietary patterns. Long-term adherence to these dietary patterns can help reduce the risk of prediabetes. Public health agencies should also promote these dietary patterns to reduce the global burden of diabetes.

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