Diabetes, Metabolic Syndrome and Obesity

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REVIEW

Effect of Dietary Approaches to Stop Hypertension (DASH) on Patients with Metabolic Syndrome and Its Potential Mechanisms

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Abstract: Metabolic syndrome (MS) is more prevalent in chronic diseases and, if left untreated, can lead to serious consequences, such as cardiovascular disease (CVD), cerebrovascular disease and type 2 diabetes, which have become significant public health issues globally. Metabolic syndrome is significantly influenced by the daily diet of patients. The dietary approaches to stop hypertension (DASH) diet, originally designed to prevent or control hypertension, offers additional metabolic benefits due to its nutrient composition. The DASH diet recommends the intake of potassium, magnesium, calcium and fibre while limiting total fat, saturated fat and sodium, which is beneficial for patients with MS. Due to its limited fat content and high levels of fibre and calcium, individuals following the DASH diet are less prone to being overweight and obese and have lower concentrations of total and low-density lipoprotein cholesterol. Moreover, the DASH diet can reduce blood pressure and is effective in correcting glucose and insulin abnormalities. This review comprehensively summarises the health benefits of the DASH diet on the risk factors of MS and describes the potential mechanisms based on available evidence.

Keywords: DASH diet, metabolic syndrome, metabolomics

Introduction

Metabolic syndrome (MS) is a major global health concern, affecting about 25% of the population, with prevalence varying significantly based on region, demographics and definitions used.[1] The most common MS components include reduced high-density lipoprotein cholesterol (HDL-C), elevated blood pressure, abdominal obesity, high triglycerides and elevated fasting glucose.[2] Metabolic syndrome significantly increases the risk of CVD and other conditions such as type 2 diabetes, non-alcoholic fatty liver disease, polycystic ovary syndrome, certain cancers, inflammatory bowel disease and chronic kidney disease.[3] Consequently, MS is linked to a higher risk of all-cause mortality.[4]

The dietary approaches to stop hypertension (DASH) diet, initially designed to combat hypertension, has demonstrated significant benefits for MS.[5] This diet recommends a high intake of fibre, potassium, calcium and magnesium while limiting total fat, saturated fat, cholesterol and sodium.[5] Unlike research that isolates single food items, DASH's holistic approach aligns more closely with real-world eating patterns.[3] Several observational studies have provided convincing evidence that greater adherence to the DASH diet significantly protects against the risk of MS and its components, including central adiposity and lipid profiles.[2,6] Clinical trials have similarly demonstrated the beneficial effects of high compliance with a DASH-style diet in protecting against the development of MS.[7,8] In this review, we discuss evidence on the effect of the dietary components of DASH on the parameters of MS.

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Metabolic Syndrome

The concept of MS was first proposed in the 1920s when it was observed that some related metabolic disorders tended to co-occur in affected individuals. Since then, institutions and organisations have proposed different definitions of MS, but without consensus. It is clear, however, that MS is a clinical syndrome involving a series of metabolic diseases, including insulin resistance, type 2 diabetes, abnormal blood pressure, dyslipidaemia and obesity.[9] These conditions in turn lead to serious clinical consequences such as CVD, cerebrovascular disease and type 2 diabetes.[10]

Dyslipidaemia includes increased serum triglyceride (TG), increased low-density lipoprotein cholesterol (LDL-C) and decreased HDL-C. Changes in these parameters may lead to liver adipocyte degeneration and destroyed pancreatic β-cells, making the body more susceptible to CVD.[11]

Another important clinical feature of MS is hypertension, which refers to a resting systolic blood pressure (SBP) of ≥140 mmHg, a resting diastolic blood pressure of ≥90 mmHg or the use of prescription drugs to control blood pressure. The presence of hypertension typically indicates arterial stenosis and is consequently considered a primary risk factor for CVD and kidney disease. Moreover, hypertension is indicated as being related to CVD, stroke and myocardial infarction.[12]

The common features of hyperglycaemia, insulin resistance and type 2 diabetes (T2D) include damaged cells being unable to ingest glucose normally, resulting in an increased level of blood glucose. Meanwhile, increased blood glucose can induce various degrees of tissue damage, which affects the average age of death of this population and the incidence of diseases such as CVD, hypertension, β-cell dysfunction, kidney diseases or blindness.[13] Diabetes is currently one of the leading causes of death in developed countries.[14]

In addition, oxidative stress and low-grade inflammation are two important mechanisms for the aethology, pathogenesis and progression of MS. Oxidative stress refers to unbalanced levels of oxidants and antioxidants in the body,[15] which will directly affect the circulatory system and ultimately lead to adverse consequences, such as atherosclerosis, the oxidation of LDL-C and the physiological dysfunction of HDL-C. Inflammation is the response of the immune system to injury. It is the main mechanism for the development and progression of obesity-related diseases, which can explain the correlation between obesity, insulin resistance, MS and CVD.[16]

According to its definition, it is obvious that MS is highly prevalent worldwide. In the past 40 to 50 years, the number of MS patients has increased in the world,[17] especially in developed countries. The incidence of MS is even higher in those with long time sitting, smoking, low socioeconomic status, an excess intake of added sugars, sodium and saturated fat and low intake of fruits and vegetables.[18]

DASH Dietary Pattern

Dietary pattern (DP), also known as eating pattern, is used to describe amounts of foods and the proportions of various foods people actually eat. Different from the traditional concepts, DP is used to assess the overall effect of daily dietary intake on diseases instead of that of a single nutrient,[19] with attention to the intricate interactions between different foods and nutrients. Based on the fact that the nutrients in foods are generally taken in a mixed form, DP can more appropriately reflect the actual diet status and better predict the risk of diseases compared with only one nutrient or food.[20]

DASH diet, as a healthy DP, can protect MS and its disease components to certain degrees.[21] The DASH DP states that a diet low in saturated fat, cholesterol and total fat helps control blood pressure. The DASH eating plan is rich in fruits, vegetables, lean meats and low-fat or fat-free dairy products while limiting total and saturated fats, cholesterol and sugar-containing products.[22] This diet is designed to address the health hazards of modern society by encouraging people to eat the minimum processed and the freshest food to reduce dietary sodium intake. In terms of nutrients, this diet is abundant in potassium, magnesium, calcium and dietary fibre and relatively low in sodium and saturated fatty acids.[23] Kang et al[24] analysed the relationship between the DASH score and MS in postmenopausal women without diabetes in South Korea and found that the incidence of MS was 0.977 times for every 1-point increase in the DASH score, and the lowest quartile of the DASH score was related to a higher prevalence of MS in postmenopausal women without diabetes. In a study on the correlation between the DASH score and MS and its components in American adolescents and young adults by Ducharme-Smith et al[25] a higher DASH score indicated a lower risk of hypertension. Nilsson et al[25]

constructed a clustered metabolic risk score according to metabolic parameters and inflammatory biomarkers and found that a higher DASH score was related to a lower clustered metabolic risk ($P<0.05$), suggesting that the DASH diet can reduce the clustered metabolic risk of the population while promoting the formation of a systemic anti-inflammatory environment in the body.

The Effect of DASH DP on MS and Related Mechanism

Blood Pressure

The aethology of hypertension is complex, and the causes and mechanisms of this disease are not established based on findings available worldwide. It is generally believed that the development of essential hypertension is based on the genetic susceptibility of individuals, with the contributions of various environmental factors, including nutritional intake, physical activity, obesity, drinking and social psychological stress, which may induce unbalanced normal blood pressure regulation and subsequent hypertension. Age is another critical factor for hypertension. An unbalanced diet, such as one that includes excessive salt intake, overconsumption of fatty foods, smoking, heavy alcohol consumption and an increased proportion of high calories, high fat and high-salt foods are all extremely critical environmental factors for the increasing prevalence of hypertension.[26]

The DASH diet is rich in fruits and vegetables, ensuring the intake of a large amount of potassium (K) while reducing the intake of sodium (Na). Studies have shown that an increased intake of K and a reduced intake of Na can help prevent the development of hypertension.[27] A diet with a high Na:K ratio increases the risk of CVD.[28] By stimulating the Na^+/K^+ ATP pump, K activates vascular smooth muscle cells, increases the activity of Na^+/Ca^{2+} exchangers and subsequently reduces the level of cytoplasmic Ca^{2+}, leading to vasodilation.[29] In addition, K^+ promotes the excretion of Na^+, reduces the sensitivity of blood vessels to norepinephrine and angiotensin II and increases insulin sensitivity to prevent excessively high levels of insulin.[27,30]

The DASH diet also contains abundant magnesium (Mg), which is beneficial for CVD. Studies have shown that a magnesium deficiency in the body is associated with an increased risk of atherosclerosis, hypertension, arrhythmia, dyslipidaemia and MS.[31,32] Magnesium exerts an antihypertensive effect by inhibiting the production of angiotensin II and aldosterone, with a mechanism as follows: (1) Mg activates the Na^+/K^+ ATP pump to reduce the levels of intracellular Na^+ and Ca;[2+33] (2) Mg increases the voltage threshold of Ca^{2+} ion channels to reduce Ca^{2+} ion exchange and, consequently, the contraction ability of vascular smooth muscle;[34,35] (3) Mg regulates vascular hardness by regulating the synthesis of extracellular structural molecules in the blood vessel wall;[34] and (4) Mg prevents vasoconstriction by inhibiting the development of inflammation in the body.[36]

The dairy products in the DASH diet also regulate blood pressure. A prospective study showed that the intake of low-fat dairy products can prevent an increase in blood pressure;[37,38] the intake of high-fat dairy products, however, can increase blood pressure.[39] Bioactive tripeptides are produced in the intestines during the digestion of casein and whey protein in dairy products, and these peptides can reduce arterial stiffness and blood pressure.[40,41] In addition, milk is also rich in potassium, which helps to lower blood pressure. Finally, dairy products, as low-glycaemic index food, can prevent oxidative stress caused by hyperglycaemia to improve the bioavailability of nitric oxide (NO) and enhance vascular function.[42]

Studies have shown that viscous soluble fibre can lower SBP;[43] the mechanism of fibre lowering blood pressure, however, remains unclear. It is generally believed that fibre improves insulin resistance and reduces the concentration of insulin, thereby lowering blood pressure.[44,45] Furthermore, insulin promotes sodium reabsorption and increases the level of Na^+ in the body.[45] Therefore, a reduced insulin concentration may be beneficial for lowering blood pressure.

Excessive intake of saturated fatty acids may increase the risk of CVD, whereas unsaturated fatty acids are beneficial for cardiovascular function.[46] Studies have shown that the intake of saturated fat is strongly related to high blood pressure.[47] However, unsaturated fatty acids inhibit the activity of angiotensin-converting enzymes by enhancing the activity of endothelial NO synthases and inhibiting the activities of pro-inflammatory cytokines and cyclooxygenase to improve NO bioavailability and vascular function.[48]

Blood Glucose

Dairy products have been shown to help prevent the development of insulin resistance and T2D, and insulin resistance is the central link in the progression of MS. A meta-analysis showed that the risk of diabetes is reduced by 8% in a population with a high intake of dairy products compared with individuals with a low intake ([RR] = 0.92, 95% confidence interval [CI], 0.86–0.97).[49] In a prospective follow-up study (4.1 years) of 3454 patients without diabetes in Spain, total dairy consumption was negatively related to the risk of T2D (RR = 0.68, 95% CI, 0.47–0.98, P_{trend} = 0.040).[50] The mechanism of dairy products in the prevention of insulin resistance and T2D remains unclear. However, available data suggest that the underlying mechanisms may involve the low glycaemic load and the high calcium (the second messenger of insulin), magnesium (a co-factor of glucose metabolism enzymes) and whey protein content in dairy products.[51,52] Calcium (100 mg/100 g) and magnesium (10 mg/100 g), which are abundant in dairy products, can help prevent the development of insulin resistance. Calcium is the medium of an insulin-mediated intracellular reaction, and the reduction of $[Ca^{2+}]i$ may affect insulin signal transduction and, subsequently, reduce the function of glucose transporters, leading to insulin resistance.[53] Magnesium is a co-factor of insulin secretion, and a magnesium deficiency may induce insulin secretion disorder, decrease insulin sensitivity, and eventually lead to insulin resistance.[54] Whey protein, accounting for approximately 20% of milk proteins, is rich in essential amino acids and branched-chain amino acids, which have been shown to promote insulin secretion and insulin sensitivity.[55] Meanwhile, it has been shown that branched-chain amino acids, particularly leucine, can promote glucose synthesis in the liver to regulate blood glucose homeostasis and insulin signalling through the mTOR pathway.[56] Alpha (α) lactalbumin is abundant in whey protein, and cysteine is high in α-lactalbumin. Cysteine is an essential amino acid for the synthesis of glutathione, which can alleviate the oxidative stress caused by diabetes and prevent the functional impairment of hepatic insulin-sensitive substances to guard against the development of insulin resistance.[57]

Studies have shown that the level of serum K^+ is negatively related to the risk of diabetes, indicating that potassium also plays a role in the prevention of diabetes.[58] Potassium may participate in the glucose-dependent insulin secretion of pancreatic B cells. The membrane of B cells is polarised by potassium efflux via ATP-sensitive K^+ channels when resting. When challenged by glucose, glucose is ingested by B cells to produce ATP, and ATP-sensitive K^+ channels are inactivated. Subsequently, the depolarisation of the B-cell membrane leads to the opening of the Ca^{2+} ion channels and the inflow of Ca^{2+}, and the intracellular Ca^{2+} concentration subsequently increases to enhance the secretion of insulin.[59] In addition, K inhibits insulin resistance induced by IL-17A, an inflammatory cytokine involved in MS.[60]

The intake of fibre has been shown to reduce the risk of diabetes,[61] and the anti-diabetic effect of fibre is possibly due to its weight-loss benefits.[62] Both soluble and insoluble fibres are beneficial for preventing diabetes. Studies indicate a stronger anti-diabetic potential of insoluble vs soluble fibre; the underlying mechanisms, however, remain unclear.[63] Insoluble fibre may play a role by increasing the secretion of glucose-dependent insulinotropic polypeptide and postprandial insulin response to reduce postprandial blood glucose.[64] In addition, a high-grain fibre diet may prevent high-protein diet-induced insulin resistance by interfering with protein absorption.[65]

Blood Lipids

Dyslipidaemia is a lipid metabolism disorder characterised by increased levels of total cholesterol, TG and LDL-C and a decreased level of HDL-C in plasma. Dyslipidaemia is recognised as an important risk factor for CVD and cerebrovascular diseases, such as coronary heart disease, atherosclerosis and hypertension.[66]

Early clinical studies have confirmed that low-fat milk is beneficial to human blood lipids. For example, Buonopane et al[67] showed that skim milk significantly reduces the levels of serum cholesterol (by approximately 6.6%) and TG (by approximately 11.8%) in individuals with high serum cholesterol (≥1.9 g/L). However, further studies showed that the dietary intake of non-low-fat dairy products (full-fat and high-fat dairy products) does not increase the risk of dyslipidaemia. Contrastingly, some studies have demonstrated that these dairy products are beneficial to the health of blood lipids.[68] For example, Engel et al[69] compared and analysed the effects of whole (fat content, 3.5%) and skim (fat content, 0.1%) milk on the levels of fasting serum lipids, insulin and plasma glucose in healthy subjects and found no significant differences in the fasting lipid, glucose or insulin levels of healthy individuals after 500 mL whole or skim milk were consumed daily; the level of HDL-C was

significantly increased among individuals with a daily intake of whole milk, compared with individuals who consumed skim milk daily. No sufficient evidence is currently available to support the concern that the intake of dairy products will increase the levels of cholesterol, LDL-C and TG. In fact, studies have found that the intake of dairy products positively affects the health of human blood lipids.[68] This is possibly explained by the abundant calcium in dairy products, which forms insoluble calcium soap with saturated fat and be discharged from the body or bind with bile to block enterohepatic circulation and trigger cholesterol circulation by upregulating LDL receptors.[56] In addition, it has been proved that phospholipids, sphingomyelins and conjugated linoleic acid in dairy products as well as lactic acid bacteria and metabolites in fermented dairy products are beneficial to human blood lipids.[56,69]

Studies have shown that fibre can reduce the levels of total cholesterol and LDD-C,[70,71] and the mechanisms related to these findings are described as follows: (1) fibre interferes with the enterohepatic circulation by inhibiting the reabsorption of bile acid in the ileum, which increases the resynthesis of bile acid and improves the utilisation of blood cholesterol; (2) fibre slows down glucose absorption to inhibit insulin response and reduce the stimulation effect of insulin on liver cholesterol synthesis; (3) fibre increases the content of LDL receptors in the liver; (4) short-chain fatty acids reduce the absorption of cholesterol in the intestine and its synthesis in the liver.[72,73] Insoluble fibre is less effective in blood cholesterol reduction compared with soluble fibre.[74]

Safety and Considerations for Implementation of the DASH Diet

Safety considerations for implementing the DASH diet include monitoring for potential electrolyte imbalances, particularly in individuals with kidney disease or those taking medications that affect potassium levels. Additionally, individuals should ensure that they meet their overall caloric needs to avoid unintended weight loss or gain. Consulting a healthcare provider before starting such a diet is recommended, particularly for those with pre-existing health conditions. Future long-term interventional studies are needed to further clarify the beneficial effects of the DASH diet on the development of MS and to ensure its safe implementation. Nevertheless, the potential health effects of the DASH diet depend on adherence to eating patterns, with individuals who had lower adherence before the intervention showing greater benefits in blood pressure control than those with higher initial adherence.[75] Commitment and patient engagement are critical in all lifestyle interventions based on dietary modifications.[76,77]

Conclusion

The DASH diet, rich in potassium, magnesium, calcium, fibre and antioxidants and low in total fat, saturated fats and sodium, has been shown to significantly protect against MS and its components, including blood pressure, blood glucose central adiposity and lipid profiles. Epidemiological, observational and interventional studies, as well as meta-analyses, support these benefits. However, the data from randomised clinical trials on the effects of the DASH diet on MS are limited, and the underlying mechanisms remain largely unknown. Future long-term interventional studies are needed to further clarify the beneficial effects of the DASH diet on the development of MS.

Data Sharing Statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Review

An ethics statement is not applicable because this study is based exclusively on published literature.

Consent for Publication

Not applicable.

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