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Unlocking the Metabolic Puzzle: Exploring the Relationship between Diet and Metabolic Syndrome

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Abstract

MetS is a complicated multifactorial syndrome resulting from complex interactions between genetic, environmental, and lifestyle factors. There are various conditions found to be associated with metabolic syndrome (MetS): low serum high-density lipoprotein, hypertension, hyperglycemia, hypertriglyceridemia, and central obesity. Deregulation of several metabolic pathways involved in glucose utilisation, mitochondrial function, and fatty acid metabolism contributes to the pathophysiology of MetS. There is a link between metabolic syndrome and a higher risk of various illnesses. The first step in managing MetS is changing one's lifestyle, which is followed by medication and change in the diet for each of the syndrome's distinct components. Reduction of body weight and following a healthy diet continue to be the cornerstone of MetS treatment. Scientific data favors the use of the Mediterranean Dietary Approaches to Stop Hypertension (DASH) diet, high protein diet and plant-based diets are the new paradigm for metabolic syndrome prevention and management. Health practitioners are able to provide simple-to-follow dietary recommendations without the need for limited diets because of the nutritional distribution and quality of these healthy meals. However, energy-restricted eating habits and low-fat diets are essential for reducing the metabolic abnormalities seen in individuals with MetS.

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INTRODUCTION

A cluster of at least three of the following five disorders is known as metabolic syndrome (MetS), that includes central obesity, hypertension, hyperglycemia, hypertriglyceridemia, and low serum high-density lipoprotein.[1-3] It is suggested that there are several contributing factors, such as ethnicity, genetic predisposition, and dietary habits.[4] Over the next five to ten years, MetS increases the risk of type 2 diabetes mellitus (T2DM) by five times and the hazard of cardiovascular disease (CVD) by two times.[1] Furthermore, people with the MetS have a 2- to 4-fold increased risk of stroke, a 3- to 4-fold increased risk of myocardial infarction (MI), and a 2-fold increased likelihood of dying from a MI, regardless of a previous history of cardiovascular events.[2,3] Recent studies have connected both the prevalence and prevention of MetS to modifiable lifestyle factors, including dietary practices. Steckhan *et al*. (2015) investigated the positive impacts of different dietary approaches on MetS inflammatory markers.[5] Godos *et al*., (2016) also conducted a meta-analysis to demonstrate how promoting healthy eating practices can aid in reducing the prevalence of MetS in relation to preventing it.[6]

CAUSES

Among the metabolic risk factors, high blood pressure, raised plasma glucose, and atherogenic dyslipidemia are the most well-known factors that may give rise to metabolic syndrome and associated disorders. Insulin resistance,[10,11] and abdominal obesity[7-9] appear to be the main underlying risk factors for the syndrome; other factors that may be linked to it, include ageing,[14] physical inactivity,[8,12,13] and hormonal imbalance.[14] Although, an unhealthy diet isn't mentioned as an underlying risk factor for the syndrome, an atherogenic diet that is, a diet high in cholesterol and saturated fat can increase a person's risk of developing cardiovascular disease.[15] According to the researches, the MetS is primarily caused by insulin resistance.[16] Without a doubt, type 2 diabetes mellitus hyperglycemia is predisposed by insulin resistance. It has also been suggested that a number of metabolic pathways connect compensatory hyperinsulinemia and insulin resistance to the other metabolic risk factors that increase the chance of developing MetS.[16,11]

DIETARY MANAGEMENT

One of the most important aspects of controlling and treating MetS is nutrition. The evidence supporting the primary prevention of cardiovascular disease by lifestyle adjustments is stronger than that supporting the importance of a healthy lifestyle for the prevention of risk factors linked to pre-diabetes and type 2 diabetes. As part of treating MetS, dietary recommendations should be centered on the whole dietary pattern because single-nutrient dietary interventions have a number of drawbacks. It is suggested that consuming reduced-fat diet is beneficial instead of high-fat diet. Nevertheless, LDL cholesterol or MetS risk factors will not be improved by switching from high-fat to reduced-fat food items.[17–19] The effects of saturated and unsaturated lipids on insulin resistance and the consequences of CVD can differ. It is discovered that the risk of CVD can be reduced by 25%, 15%, and 9%, respectively, by substituting equivalent energy intake from PUFA, monounsaturated fatty acids (MUFA), or high-quality carbohydrates (whole grains, but not refined starches or added sugars) for 5% of energy intake from saturated fatty acids.[20] Furthermore, it has been found that polyunsaturated fats have cardio-protective advantages against hypertension and CVD among people.[21] The application of wholesome food-based dietary treatments for MetS is supported by recent research. Maintaining a healthy weight and other MetS diet associated risk factors is made easier by adhering to a balanced diet and exercise programme. A brief discussion of how different diets can avoid the metabolic syndrome has been included in this article.

Mediterranean Diet

The food habits, customs, and cooking methods followed by the nations and people residing in the Mediterranean Sea region are collectively referred to as the "MedDiet".[22] The MedDiet is a plant-based diet that emphasises fruits, whole-grain cereals, nuts, legumes, lentils, and leafy green vegetables as well as extra virgin (cold-pressed) olive oil as the primary source of fat. Additionally, traditional dishes are enhanced by condiments like sofrito, which mostly consists of olive oil, tomato, garlic, onion, or leek and is high in carotenoids and phenolic compounds including lycopene, β-carotene, hydroxy-tyrosyl, and naringenin.[23] A low to moderate intake of seafood is another feature of the Mediterranean diet, as does a modest consumption of fermented alcoholic beverages like red wine, typically during meals.

A high-fat, low-carbohydrate (CH) diet, the classic Med Diet supplies 35–45% of daily energy intake from fat, approximately 15% from protein, and 40–45% from carbohydrate.[12,26] Regarding CVD, the Med Diet has been linked to statistically significant decreases in the likelihood of experiencing the primary CVD endpoints, such as stroke and coronary heart disease.[27] In addition, the Med Diet has helped lower the occurrence of T2DM and CVD while also reducing the severity and related consequences in those who have already received a diagnosis.[24,25,28-30,36] Because of the health benefits associated with this straightforward eating plan, the Med Diet should be considered one of the first therapeutic options for the prevention and control of.

High-Protein Diet

Modulating whole food protein sources, total dietary protein as a percentage of energy, and amino acid supplementation can all positively affect MetS and related problems. In a recent study, the effects of normal (0.8 g protein.kg–1day–1) and high protein (1.4 g protein/kg/day) on MetS parameters were examined in overweight/obese males who followed a 12-week diet low in energy (–750 kcal/day). During the intervention, there was no change in blood pressure or resting energy expenditure, and all patients showed improvements in their body composition and markers of insulin resistance and dyslipidemia. However, the high protein group lost less lean body mass than the regular protein group.[31] Evidence suggests that in older populations with MetS, higher protein intake during periods of calorie restriction is necessary to maintain adequate protein balance. The source of dietary protein also appears to influence MetS-related outcomes. For instance, in a fructose-induced rat model of MetS, sardine protein was found to be more effective than casein in improving insulin resistance, reducing inflammation, and lowering oxidative stress in adipose tissue.[33] Similar benefits were observed when comparing sardine powder-fed animals to those fed casein or standard chow. In human studies, short-term supplementation with cod protein (four weeks) in insulin-resistant men and women was associated with reduced C-reactive protein (CRP) levels,[34] and improved insulin sensitivity.[35] However, cod protein was less effective in lowering total cholesterol, LDL-C, and apolipoprotein B concentrations compared to diets rich in animal protein sources such as beef, pork, veal, eggs, and dairy products.[34]

Plant-Based Dietary Patterns

Plant-based dietary patterns encompass a diverse range of eating habits characterized by increased consumption of plant-derived foods such as whole grains, fruits, vegetables, nuts, legumes, and legume-based products alongside a reduced intake of animal-based foods. Variations within these diets include pesco-vegetarians (pescatarians), who are similar to lacto-ovo-vegetarians but include fish; vegan diets, which exclude all animal products including dairy, eggs, and honey; lacto-vegetarian diets, which exclude all animal foods except dairy; and lacto-ovo-vegetarian diets, which exclude meat, poultry, and seafood but allow eggs and dairy. The health-promoting effects of plant-based diets are primarily attributed to their higher nutritional quality, emphasizing a wide variety of plant foods while limiting animal products particularly red and processed meats associated with an

elevated risk of T2DM, CVD, and certain cancers.[37] Due to their high fiber content and low energy density, plant-based diets can aid in the prevention of CVD, support weight loss, and help maintain a healthy body weight over the long term.[38-40] Additionally, the antioxidant properties of vitamins (C and E), β-carotenes, and polyphenols present in plant foods contribute to reduced risk of CVD and MetS.[41-43]

Low-carbohydrate diet

Dietary patterns classified as low carbohydrate typically involve consuming less than, 50% of total daily calories from carbohydrates. Such diets recommend restricting starches, refined grains, ultra-processed foods, and items high in simple or added sugars.[44] However, evidence linking carbohydrate intake with the prevalence and management of MetS remains inconsistent. In a meta-analysis of 18 studies involving 69,554 patients with MetS, Lui *et al.* (2019) reported that each 5% increase in energy derived from carbohydrates was associated with a 2.5% higher likelihood of developing MetS (95% CI: 0.4–4.8).[45] High carbohydrate consumption was also associated with adverse lipid profile changes, including elevated blood pressure, triglycerides, LDL cholesterol, and reduced HDL cholesterol.[46,47]

The benefits of low carbohydrate diets are thought to arise from reducing rapid carbohydrate absorption particularly from glucose and refined grains—which otherwise promote insulin resistance and increased insulin demand.[48,49] As such, recent clinical guidelines emphasize dietary individualization in T2DM management, without prescribing a strict carbohydrate distribution or restriction. In a randomized controlled trial (RCT), Bazzano *et al.,* (2014) compared a low-fat diet (<30% of total energy from fat, <7% saturated fat) with a low-carbohydrate diet (<40% of total energy from carbohydrate) in obese adults (BMI 30–45 kg/m^2), without requiring physical exercise. After one year, participants in the low carbohydrate group, despite no caloric restriction, experienced greater weight loss (3.5 kg; 95% CI: 5.6 to 1.4 kg) and fat mass reduction (1.5%; 95% CI: 2.6–0.4%). Furthermore, they showed improvements in several cardiovascular risk factors, including triglycerides, HDL-c, and the total cholesterol/HDL-c ratio.[50] With respect to T2DM, interventions involving carbohydrate restriction have demonstrated greater improvements than low-fat dietary interventions (<30% of total energy from fat) in reducing glycemic levels and associated risk markers.[51,52]

Low-fat diet

The quality of dietary fat influences insulin sensitivity and resistance in healthy, obese, and diabetic people as well as their chance of developing diabetes. Elevated serum levels of saturated fatty acids (SFA) have been linked to the onset of MetS,[53] whereas vegetable fat, intakes of polyunsaturated fatty acids (PUFAs), and elevated serum levels of ω-6 (n-6) PUFAs have been found to be negatively correlated with the risk of diabetes.[54,55] Higher intakes of polyunsaturated fatty acids (PUFA) significantly decreased the incidence of type 2 diabetes, but neither saturated nor monounsaturated fat consumption was linked to the condition in a large prospective cohort of women followed for 14-years.[56] Saturated and trans fatty acids have been shown in a large number of studies to negatively impact metabolic health.[57,58] On the other hand, unsaturated fatty acids, enhance metabolic parameters like blood pressure, lipid profile, insulin sensitivity, and glucose management.[59,60]

CONCLUSION

The MetS is a group of components or risk factors associated with an increased risk of CVD and T2D. MetS is also linked to several other comorbidities, including microvascular disease, sleep difficulties, reproductive tract issues, and non-alcoholic fatty liver disease. Treatment or prevention of the MetS, and its components should primarily focus on changing one's lifestyle and losing weight. It is commonly known that treating all of the MetS consequences, such as excessive obesity, dyslipidemia, hypertension, insulin resistance, and hyperglycemia, can be achieved with weight loss along with diet and exercise. The best chance of achieving these objectives may lie in focusing on therapeutic initiatives and treating insulin resistance and extra fat with nutritious diets. Health care providers should focus on supporting patients with MetS by promoting balanced nutrition and integrating healthy meal patterns into daily life. Instead of restricting a single nutrient, the protective effects against MetS appear to result from the cumulative impact of multiple small dietary modifications. Current scientific evidence highlights, the Mediterranean Diet as an effective paradigm for both prevention and management of MetS, demonstrating greater benefits compared to low-fat or highly restrictive diets. RCTs evaluating low-carbohydrate, Mediterranean-style diets particularly those encouraging plant-based proteins, and whole grains may provide additional strategies for effectively managing MetS.

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