Dietary Strategies for Metabolic Syndrome: A Review

Castro-Barquero S1, Ruiz-León AM1,2, Sadurní M1,2, Estruch R1,2, Casas R1,2*

Abstract
Metabolic syndrome is a cluster of metabolic abnormalities that includes abdominal obesity, atherogenic dyslipidemia (elevated plasma triglycerides and reduced high-density lipoprotein cholesterol), elevated blood pressure and insulin resistance, which can manifest as elevated fasting plasma glucose. Patients classified as having metabolic syndrome are at increased risk for developing chronic diseases, including type 2 diabetes mellitus and cardiovascular diseases. Lifestyle modification is generally recognized as a key intervention in metabolic syndrome; however, the complex nature of this condition complicates treatment strategies. Specific dietary alterations have been shown to improve the metabolic derangements that constitute metabolic syndrome therefore dietary intervention is a primary focus of treatment. Nonetheless, the most effective dietary pattern for the treatment of metabolic syndrome has not yet been established. On the other hand, within the context of the overweight and obesity epidemic that is currently a global public health crisis, reducing caloric intake and increasing physical activity to achieve weight loss can improve the metabolic abnormalities observed in metabolic syndrome. The present review aims to analyze different dietary patterns with potential benefits on metabolic syndrome status in order to identify efficient strategies to fight against metabolic syndrome and associated diseases.

Keywords
Metabolic syndrome; Cholesterol; Food pattern

Abbreviations: MetS: Metabolic Syndrome; LFD: Low Fat Diet; MedDiet: Mediterranean Diet; VLCD: Very Low Carbohydrates Diets; KD: Ketogenic Diets; HPD : High Protein Diet; CH : Carbohydrates; DASH diet: Dietary Approaches To Stop Hypertension Diet; ND: Nordic Diet; SAD: Standard American Diet; VCAM-1: Vascular Cell Adhesion Molecule 1; ICAM-1: Intercellular Adhesion Molecule 1; LDL: Low Density Lipoprotein; HDL: High Density Lipoprotein; CVD: Cardiovascular Disease; T2DM: Type 2 Diabetes Mellitus; FBG: Fasting Blood Glucose; BP: Blood Pressure; MUFAs: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids; EVOO: Extra Virgin Olive Oil; LDL-c: Low Density Lipoprotein Cholesterol; HDL-c: High Density Lipoprotein Cholesterol; HbA1c: Glycated Hemoglobin; BMI: Body Mass Index; RCT: Randomized Controlled Trial

Introduction
Unhealthy dietary patterns and a sedentary lifestyle have an important role in human health, especially nowadays, when non-communicable diseases such as obesity, cardiovascular disease (CVD) and type 2 diabetes mellitus (T2DM) have somewhat unseated communicable diseases practically worldwide, despite the incidence of the former being higher in developed and developing countries [1].

In this context, high blood pressure (BP), altered blood lipid levels, excessive weight characterized by central adiposity, and abnormally high fasting blood glucose (FBG) concentrations are a cluster of metabolic risk factors that often appear together or in different combinations. In 1998 the World Health Organization (WHO) and subsequently, other health organizations defined this group of metabolic risk factors as metabolic syndrome (MetS), and with the exception of some details the criterial definitions of these organizations coincide [2-4]. MetS is met when at least three of the following factors are present: elevated triglycerides (≥150 mg/dL), reduced high-density lipoprotein cholesterol (LDL-c <40 mg/dL in males and <50 mg/dL in females), elevated FBG (≥100 mg/dL), elevated BP (systolic BP ≥ 130 and/or diastolic BP ≥ 85 mm Hg), and elevated waist circumference (with country-specific definitions). In addition, pharmacologic treatment of any of these criteria (except waist circumference) must also be taken in account [4].

The prevalence of this complex health condition is high [5]. Studies in the last years have reported that MetS affects around 20-30% of the population [6-9]. These data are worrisome considering the relationship between MetS and the increased risk to develop other diseases. Indeed, Dragsbæk et al. described a 6.3-fold increase in the risk of developing T2DM and a 1.7-fold increase in the risk of CVD in older women with MetS while older women without MetS had a 3.6-fold and 1.3-fold increase, respectively, being these results similar to those described by Alberti et al. MetS has also been associated with depressive disorders, alterations in circadian rhythm, erectile dysfunction and colorectal cancer [4,10-15]. Although the etiology of MetS remains unknown, it has been described as being dependent on other factors such as genetic background, age, sex, ethnicity, environmental factors (urban or rural settings), socioeconomic status, physical activity, smoking habit, education and diet [16,17].

Treatment of MetS is focused on improving lifestyle by following a healthier dietary pattern and promoting physical activity. In their meta-analysis Yamaoka and Tango concluded that lifestyle intervention is effective in achieving a significant reduction in systolic and diastolic BP, triglyceride levels, waist circumference and FBG [18]. They suggested that dietary modifications could be a more effective intervention than physical activity [18]. Taking into account the relevance of MetS in health status, the aim of this review was to describe the potential benefits of different dietary patterns on MetS status in order to identify efficient strategies for its prevention, management and control of associated diseases.

Dietary patterns
Specific dietary alterations have shown to improve the metabolic derangements that constitute MetS. Therefore dietary intervention is a primary focus of treatment, even though the most effective dietary pattern for the treatment of MetS has not yet been established. Table 1 shows the different diets implemented and their positive effect on MetS criteria.

Table 1 shows the different diets implemented and their positive effect on MetS criteria.
benefit in the long term [22].

Low-fat diet, this dietary approach resulted in no cardiovascular
group. Despite the improvement in MetS status the first year of the
6 years). On the other hand, the need for cholesterol-lowering or
associated with improvement in the components of MetS at 1 year
without a dietary intervention [20,21]. The LFD was significantly
women aged 50-79 years were randomized into two intervention
and 6-8% polyunsaturated fatty acids (PUFA). This reduction in fat
is <10% saturated fat, 12-14% monounsaturated fatty acids (MUFA)
■ Total fats 30% kcal/d
■ Saturated fats <10% kcal/d
■ Carbohydrates 50-60% kcal/d
■ Refined sugars <10% kcal/d
■ Proteins 10-20% kcal/d

Reduction of diastolic BP [50]

Metabolic syndrome, MetS; blood pressure, BP; low-density lipoprotein cholesterol, LDL-c; high-density lipoprotein cholesterol, HDL-c, type 2 diabetes mellitus, T2DM; glycated hemoglobin, HbA1c; monounsaturated fatty acids, MUFA; polyunsaturated fatty acids, PUFA; fasting blood glucose, FBG.

Low-Fat Diet

Low-fat diet (LFD) is the leading dietary intervention to
reduce the complications related to MetS. In fact, the dietary
recommendations for weight loss of the American Heart Association
and the National Institute of Health emphasize the importance of
low-fat and high-carbohydrate dietary patterns [19]. By definition,
LFD comprises <30% kcal/day from total fat, and the profile of this fat
is <10% saturated fat, 12-14% monounsaturated fatty acids (MUFA)
and 6-8% polyunsaturated fatty acids (PUFA). This reduction in fat
is substituted by high-carbohydrate intake or high-PUFA fatty acid
diets. In the scientific statement for the diagnosis and management of
the MetS of the American Heart Association and National Heart,
Lung, and Blood Institute [20], the atherogenic diet was proposed
in patients with MetS. This diet reduces the fat content to 25-35% of
total calories and includes <7% of saturated fat, <200 mg/d of dietary
cholesterol and a reduction of trans fat intake. Although LFD is the
leading nutritional strategy for MetS treatment, a very LFD should be
avoided if elevated triglycerides or low HDL-c levels are present [19].

In the Women’s Health Initiative (WHI), 48,835 postmenopausal
women aged 50-79 years were randomized into two intervention
groups: one following a LFD (<20% of kcal/d from fat) and another
without a dietary intervention [20,21]. The LFD was significantly
associated with improvement in the components of MetS at 1 year
of intervention but not during the remainder of the follow-up (at 3
and 6 years). On the other hand, the need for cholesterol-lowering or
hypertension medication was significantly reduced in the intervention
group. Despite the improvement in MetS status the first year of the
LFD intervention, this dietary approach resulted in no cardiovascular
benefit in the long term [22].

On the other hand, other randomized clinical trials, including the
PREDIMED study [23], have compared different dietary strategies
with a LFD and found greater long-term cardiometabolic benefits
(insulin resistance, BP and dyslipidemia) with the other dietary
interventions.

Mediterranean Diet

The Mediterranean diet (MedDiet) is characterized by a high
consumption of food of vegetable origin, such as fruits, vegetables,
legumes, nuts and whole-grain cereals; with extra virgin olive oil
(EVOO) as the principal source of fat; consumption of low-to-
moderate amounts of fish and poultry; low consumption of red meat;
moderate consumption of red wine; normally with meals, and tomato
sauce with garlic, onion and EVOO used for meal preparation [24]. High
adherence to a Mediterranean-style diet has been consistently linked to
favorable health outcomes and has a beneficial influence on the metabolic
pathways leading to MetS and T2DM, as well as CVD [25].

As the main key foods of the MedDiet, EVOO is a lipid extract from
olives, whereas nuts are whole foods that provide additional non-lipid
nutrients, including fiber; arginine, the precursor of the endogenous
vasodilator nitric oxide; and minerals, such as potassium, calcium
and magnesium [26]. Besides EVOO and nuts, the high content of
vegetables and fresh fruits of the MedDiet, together with a moderate
consumption of wine, guarantees a high intake of antioxidant
vitamins and phenolic compounds. Indeed, previous reports from the
PREDIMED trial (Prevención con Dieta Mediterránea), a parallel-
group, multicenter, randomized trial including individuals aged 55-80
years at high risk of cardiovascular disease, showed that MedDiets are
associated with improved insulin resistance and decreased oxidative

Table 1: Dietary patterns and the potential positive effect on MetS criterias.

<table>
<thead>
<tr>
<th>Dietary Pattern</th>
<th>Nutritional Distribution</th>
<th>Improvements In Mets Criteria</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-fat diet</td>
<td>■ &lt;30% kcal/d from total fat (&lt;10% of saturated fat)</td>
<td>Weight-loss and reduction of abdominal obesity</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>■ 45-50% kcal/d from carbohydrates</td>
<td>Decreased BP (systolic and diastolic)</td>
<td>[20]</td>
</tr>
<tr>
<td></td>
<td>■ 30-35% kcal/d from total fat (main source are EVOO and nuts)</td>
<td>Decreased LDL-c</td>
<td>[19,20,55]</td>
</tr>
<tr>
<td></td>
<td>■ 20% kcal/d from protein</td>
<td>Improved insulin resistance</td>
<td>[27]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of the incidence of T2DM</td>
<td>[29]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased BP (systolic and diastolic)</td>
<td>[56]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improvements in dyslipemia</td>
<td>[56]</td>
</tr>
<tr>
<td>Mediterranean diet</td>
<td>■ 45-50% kcal/d from carbohydrates</td>
<td>Weight-loss and weight-loss maintenance</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td>■ High protein (20-30% kcal/d)</td>
<td>Reduction of DBP</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td>■ High fat intake (60-70% kcal/d)</td>
<td>Reduction of LDL-c and triglycerides levels</td>
<td>[33,34]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improvements in FBG</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improvements in insulin resistance</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of HbA1c levels</td>
<td>[33,34]</td>
</tr>
<tr>
<td>Very low carbohydrate diets or Ketogenic diet</td>
<td>■ &lt;10% kcal/d from CH</td>
<td>Weight-loss maintenance</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td>■ High protein (20-30% kcal/d)</td>
<td>Reduction of diastolic BP</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td>■ High protein (20-30% kcal/d or 1.34 g/Kg body weight/d from protein)</td>
<td>Reduction of systolic BP</td>
<td>[48]</td>
</tr>
<tr>
<td></td>
<td>■ Low carbohydrate (40-50% kcal/d)</td>
<td>Reduction of insulin levels</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction of triglycerides, FBG, weight</td>
<td>[50]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increment of HDL-c</td>
<td>[50]</td>
</tr>
<tr>
<td>High protein diet</td>
<td>■ High protein (20-30% kcal/d)</td>
<td>Reduction of diastolic BP</td>
<td>[54]</td>
</tr>
<tr>
<td></td>
<td>■ Low carbohydrate (40-50% kcal/d)</td>
<td>Weight-loss</td>
<td>[38,39,40,42]</td>
</tr>
<tr>
<td>DASH diet</td>
<td>■ Total fats 27% kcal/d</td>
<td>Reduction of diastolic BP</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td>■ Saturated fats 6% kcal/d</td>
<td>Reduction of systolic BP</td>
<td>[48]</td>
</tr>
<tr>
<td></td>
<td>■ MUFA 13% kcal/d</td>
<td>Reduction of insulin levels</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td>■ PUFA 9% kcal/d</td>
<td>Reduction of triglycerides, FBG, weight</td>
<td>[50]</td>
</tr>
<tr>
<td></td>
<td>■ Carbohydrates 55% kcal/d</td>
<td>Increment of HDL-c</td>
<td>[50]</td>
</tr>
<tr>
<td></td>
<td>■ Proteins 18% kcal/d</td>
<td>Reduction of diastolic BP</td>
<td>[54]</td>
</tr>
<tr>
<td>Nordic diet</td>
<td>■ Total fats 30% kcal/d</td>
<td>Weight-loss</td>
<td>[33]</td>
</tr>
<tr>
<td></td>
<td>■ Saturated fats &lt;10% kcal/d</td>
<td>Reduction of diastolic BP</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td>■ Carbohydrates 50-60% kcal/d</td>
<td>Reduction of systolic BP</td>
<td>[48]</td>
</tr>
<tr>
<td></td>
<td>■ Refined sugars &lt;10% kcal/d</td>
<td>Reduction of insulin levels</td>
<td>[47,50]</td>
</tr>
<tr>
<td></td>
<td>■ Proteins 10-20% kcal/d</td>
<td>Reduction of triglycerides, FBG, weight</td>
<td>[50]</td>
</tr>
</tbody>
</table>
With MetS. A high protein diet provides approximately 20-30% kcal of the total kcal/d, which can be translated to 1.34g/Kg body weight/ day from protein [38-40]. This dietary pattern may contribute to the maintenance of lean body mass during a period of energy restriction, helping to preserve resting energy expenditure and increase the thermic effect of feeding [39,41].

In a recent randomized controlled study comparing a high protein diet with a standard protein diet (0.8g/Kg body weight/day) in the treatment of the MetS, no significant differences were observed except in weight loss. It has been reported that a high protein diet does not affect insulin sensitivity, and even with an increase of physical activity, a study including overweight and obese middle-aged adults showed no significant changes in the MetS-related parameters [38,40,42].

In another study including women at risk of developing MetS, significant improvements were observed in those who followed a high protein weight-loss diet (500-900 kcal restriction per day) compared to a high fiber intake diet. This was further demonstrated in a second analysis of the original study in which a double-blind, placebo-controlled, community-based 36-week intervention was performed in women at risk of MetS [43]. Blood pressure as well as total and LDL-c levels decreased and insulin sensitivity increased, but no significant differences were observed between the two intervention groups [39].

However, according to the results of a randomized 3-period crossover feeding trial [complementary study of the Omni Heart trial [38], and a randomized 24-month intervention study in the US, there is some controversy about the effect that a high protein diet may have on the glomerular filtration rate and the possibility of presenting long-term consequences in kidney function [41,44]. Further studies are needed to confirm the safety of this dietary pattern.

DASH Diet

The Dietary Approach to Stop Hypertension (DASH diet) has demonstrated to be effective in BP management [45]. This diet is characterized by a high intake of fruits and vegetables and a low consumption of high-fat dairy products [45,46]. This diet has a reduced content fat, especially of saturated fats and dietary cholesterol, and sodium intake is reduced to approximately 3g per day [45,46].

A randomized cross-over clinical trial in female adolescents diagnosed with MetS found a significant reduction of diastolic BP (-1.9% vs +4.4% respectively, P=0.01) insulin levels (-10.4%, P=0.04) when the DASH diet was followed during 6 weeks compared to the usual dietary recommendations. However, there were no differences in insulin levels between the two interventions, and weight, waist circumference, BMI and systolic BP remained unchanged [47]. Conversely, analyzing a subgroup of individuals with the MetS from the DASH trial, Hikmat and Appel reported that systolic BP was significantly lower following the DASH diet compared to the control diet (4.9 mm Hg, P=0.006) but not diastolic BP (1.9 mm Hg, P=0.15) [47]. A randomized controlled trial (RCT) involving a tailored DASH nutritional intervention with the supplementation of ω-3 fatty acids in elderly women, showed a significant decrease in LDL-c levels in the women receiving the intervention but no differences in the control group [48]. In a randomized, parallel study Hill et al. compared three modified DASH diets associated with calorie restriction with the American diet (high in total and saturated fat, cholesterol, sodium and lower in fiber, potassium, calcium and magnesium) [49]. They found improvements in MetS components with the three calorie-restricted diets compared to the American diet but there were no...
significant differences in systolic and diastolic BP (P = 0.28 and P = 0.122) [54]. On the contrary, in another study, after 18-week intervention with the Nordic diet compared to controls, a significant improvement was observed in diastolic BP (-4.4 mm Hg, P = 0.004) in the intervention group and 0% in the control group (P < 0.05) [50]. Accordingly, the DASH diet seems to be effective in MetS management, especially in relation to high BP levels.

**Nordic Diet**

The Nordic diet comprises a high content of whole-grain and high-fiber products (rye, barley, oat, unpolished rice), has a substantial quantity of fruits, vegetables, berries and nuts, is rapeseed oil-based, includes low-fat dairy products, and it is characterized by an elevated fish and shellfish intake [51,52]. Total fats make up approximately 30% of the total energy intake, saturated fats must not exceed 10% of total energy, carbohydrates represent 50-60% of energy intake, the refined sugar intake is less than 10% of total energy intake, and the protein content is between 10-20% of daily total energy intake [51]. This diet has been related to improvement in CVD risk factors [53].

In a study including 18 subjects with MetS undergoing a 3-month intervention with the Nordic diet compared to controls, a significant improvement was observed in diastolic BP (-4.4 mm Hg, P = 0.001) and mean arterial pressure (-4.2 mm Hg, P = 0.006) in the intervention group, but systolic BP showed no significant improvement (-3.5 mm Hg, P = 0.122) [54]. On the contrary, in another study, after 18-24 weeks of intervention with Nordic diet, 96 subjects showed no significant differences in systolic and diastolic BP (P = 0.28 and P = 0.29 respectively) or weight loss (P = 0.097) [52]. Nevertheless, significant improvements were observed in non-HDL-c (-6.85 mg/dL, P = 0.004) [52]. In view of the lack of scientific evidence related to the benefits of the Nordic diet, more RCTs are needed.

**Conclusion**

The results of several studies suggest the potential benefits of healthy dietary patterns and lifestyle modification on MetS status. The protective effect of energy-restricted diets on MetS status seems to be due to the sum of small changes in individual components of MetS rather than a large effect on any single component. This lifestyle intervention must be focused on modification in weight-loss and physical activity in order to achieve significant improvements. The aim of this review was to describe different nutritional patterns with potential benefits in MetS status in order to facilitate new dietary strategies, which have obvious implications for the primary prevention of major cardiovascular events and provide a good public health strategy to fight against MetS and overweight.

On comparing the LFD, which is the gold standard dietary pattern for MetS treatment, with other dietary patterns, the scientific evidence in favor of the MedDiet may make this diet a new paradigm for MetS treatment. The nutritional composition of the MedDiet pattern, the fat content, the composition of fatty acids and the quality of the carbohydrates allows health professionals to provide easy-to-follow nutritional advice and avoid the use of restricted diets.

**Acknowledgment**

This work has been partially supported by PIE14/00045 from the Instituto de Salud Carlos III, Spain. CIBER OBEN is an initiative of the Instituto de Salud Carlos III, Spain. Castro-Barquero S, Ruiz-León AM and Sadurní-Puig M substantially contributed to the conception and design and the drafting of the article; Estruch R and Casas R critically revised the article for important intellectual content; and Castro-Barquero S, Ruiz-León AM, Sadurní-Puig M, Estruch R and Casas R approved the final version of the manuscript for publication.

**References**


Author Affiliations
1Department of Internal Medicine, Hospital Clinic, University of Barcelona, Spain
2Ciber Fisiopatología de la Obesidad y la Nutrición (CIBEROBN), Instituto de Salud Carlos III, Spain