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Current evidence on the association of the metabolic syndrome and dietary patterns in a global perspective

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Abstract

The metabolic syndrome (MetS) is a key indicator of two main causes of death worldwide: CVD and diabetes. The present paper aimed to perform a review of the population-based research on the association of dietary patterns and the MetS in terms of methodology and findings. For the purpose of the present study, a scoping literature review was conducted using MEDLINE and EMBASE databases and hand searching in Google Scholar. Thirty-nine population-based studies were selected. Most of these studies used the factor analysis method and the *a priori* dietary approach, which had been initially extracted via *a posteriori* methods such as using the Mediterranean dietary pattern. The main finding was that following the Mediterranean or similar 'healthy' pattern reduced risk of the MetS, while following a 'Western' pattern increased risk of the MetS. The methodological approach in determining the dietary pattern of a population, whether *a priori* or *a posteriori*, should be chosen based on the purpose of the research. Overall, evidence suggests a diet based on the components of the Mediterranean diet and the avoidance of the 'Western' diet can aid in preventing the MetS.

Key words: Metabolic syndrome: Dietary patterns: Mediterranean diet: Western dietary pattern

Introduction

Two main causes of death and morbidity in the world are CVD and diabetes. The metabolic syndrome (MetS) is a cluster of important risk factors related to these diseases, including central obesity, dyslipidaemia, elevated fasting plasma glucose and hypertension. Having the MetS increases the risk of developing CVD and diabetes by two and five times, respectively[1]. Genetics, physical activity and diet are known key factors to make an impact on the status of this syndrome. The National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III) and the American Heart Association have recommended diet-based plans as one principal approach to prevent metabolic disorders predisposing to CVD[2,3].

Diet is composed of interacting and inter-correlated nutrients, making it challenging to identify the influence of each nutrient independently[4]. Moreover, metabolic disorders including the MetS have been shown to have an association with food and dietary patterns rather than nutrients, with a few exceptions such as vitamin D[5–7]. Researchers have been successful in reducing the risk of MetS development when using an overall diet modification approach in interventional trials[8]. Therefore, exploring dietary patterns with regards to the MetS may be a beneficial way to understand the impact of diet on the MetS[4].

Dietary patterns are determined based on two main approaches including the *a posteriori* and *a priori* methods[9]. In the *a posteriori* approach, derived data are applied in multivariate statistical approaches to explain the inter-correlation of food or food groups. This approach includes cluster analysis, common factor analysis and principal component analysis as well as new approaches such as reduced ranked regression and partial least squares regression[10]. In the second main analytical approach, the *a priori*, existing food/food group knowledge, guidelines and recommendations, and healthy known dietary patterns are used to develop indices[11,12].

Researchers have evaluated the association between dietary patterns and the MetS using different study designs including randomised controlled trials (RCT) and population-based studies[13]. Kastorini *et al.*[13] have conducted a meta-analysis to evaluate the association of the MetS and Mediterranean diet using both population-based studies and clinical trials published up to 2010. The updated systematic review by Esposito *et al.*[14] in 2013 confirms their previous results (Kastorini *et al.*[13]). Further, Calton *et al.*[15] conducted a review on the literature from 2000 to 2012 including prospective studies and RCT to evaluate the beneficial dietary patterns that have a protective role on MetS status with emphasis on the contribution of these patterns in the Asia–Pacific region. They have also concluded the beneficial effects of the Mediterranean diet, Nordic diet and Dietary Approaches to Stop Hypertension (DASH) diet and the need for further RCT to investigate their effect for the future. High-standard RCT are the most valuable evidence for inferring causality. However, we chose to focus on population-based studies where subjects are consuming their usual self-selected diets for two reasons. First, this allows

Abbreviations: DASH, Dietary Approaches to Stop Hypertension; MetS, metabolic syndrome; NCEP-ATP III, National Cholesterol Education Program Adult Treatment Panel III; RCT, randomised controlled trial.

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investigation of 'real-world' populations with different characteristics[16,17]. Second, population-based studies help in understanding the dietary patterns that are prevalent among a population and their association with the MetS. This focus would contribute to understanding the real-life dietary practices of populations upon which dietary recommendations can be structured[18].

The association between the MetS and dietary patterns, however, has not been recently evaluated using population-based studies. Furthermore, the methodologies to extract the dietary patterns among populations have not been categorised and compared within this context. Therefore, the objective of this research study is to perform a scoping review of the most recent evidence on the association between dietary patterns and the MetS using population-based studies. A secondary aim was to identify commonly used methodological approaches for investigating dietary patterns and justifications behind them among population-based studies in developed and developing countries.

Methodology

For the purpose of the present review, a scoping literature review was conducted using the framework provided by Arksey & O'Malley[19]. A scoping review, a tool to understand the available knowledge of a field[20], includes the following steps: identifying the studies based on the research question; selecting studies and charting the data; and, finally, summarising the results[19]. We conducted the review based on the following research question: what is the relationship between dietary patterns and the MetS among populations comparing two common methods of dietary pattern approaches including the *a priori* and the data-driven approaches?

The inclusion criteria considered for this review study were: (1) published full-text articles between 2005 and 2014 (inclusive); (2) studies that investigated the association between MetS status and dietary patterns (using *a priori*-defined and/or data-driven analytical approaches); (3) population-based studies including cohorts and cross-sectional-designed studies with a sample size of more than 300 individuals; and (4) English-language journals. Exclusion criteria were: (1) studies that have used uncommon dietary pattern analytical approaches (for example, reduced ranked regression and partial least square); (2) studies that have focused on a special migrated ethnicity to another country; and (3) review articles.

The search was conducted using three electronic databases including MEDLINE, EMBASE and hand searching in Google Scholar. As well, the bibliographies of relevant articles were evaluated. Initially, the combination of keywords/subject headings of 'metabolic syndrome', 'metabolic syndrome X', 'insulin resistance syndrome' with general terms of the topic including 'diet' and 'dietary pattern' or specific dietary pattern methods including the following terms: 'factor analysis', 'cluster analysis', 'reduced rank regression', 'partial-least square regression', 'dietary index', 'Mediterranean diet', 'Healthy Eating Index', 'DASH/Dietary Approaches to Stop Hypertension', 'Dietary Guidelines for American Index' and 'vegetarian diet' were searched. The identified studies were evaluated in terms of inclusion and exclusion criteria by the three authors independently (Z. H., H. V. and S. W.). In case of disagreement, discussion led to consensus among the authors. The selection procedure was done starting from evaluating the title, abstract and full text. The subject headings/keywords used to conduct the search in MEDLINE and EMBASE are included in the Supplementary document.

Results

Characteristics of studies

From a total of 4660 records screened (2560 records from MEDLINE and EMBASE and 2100 records from hand searching in Google Scholar), ninety-eight full-text articles were assessed for eligibility. A total of thirty-nine studies, published from 2005 to 2014, met the inclusion criteria and were included in the present review. Seven of these epidemiological studies had longitudinal[21–27] design and the remaining (n 32) had a cross-sectional design. The studies were conducted in twenty-three different countries including Algeria[28], Australia[29], Bulgaria[28], China[30], Egypt[28], Finland[31], France[25], Germany (n 2)[32,33], Greece (n 4)[28,34–36], Guatemala[37], Iran (n 3)[38–40], Italy (n 3)[28,41,42], Japan[43], Korea (n 4)[44–47], Lebanon[48], Mexico[49], Portugal[50], Samoa[51], Serbia-Montenegro[28], Spain[52], Sweden[53], Taiwan[26] and the USA (n 10)[3,21–24,54–58]. The studies enrolled from 323[48] to over 93 209[26] participants.

Study populations

General adult populations over the age of 18 years were mainly studied. In addition, the middle-aged and/or elderly population, which included individuals over 45 years of age, was the focus of four studies[23,30,38,42]. Only two studies[29,58] evaluated the association of the MetS and dietary patterns among adolescents. Five studies included only women[3,22,38,40,45], one study included only men[55] and the remaining included both sexes as their participants.

Measurement of the metabolic syndrome

The NCEP-ATP III criteria[2] or its adjusted or modified versions were mainly used to evaluate the MetS. However, some studies used the joint 2005 International Diabetes Federation (IDF) and American Heart Association criteria[1] and other studies used the IDF criteria[59] to define the MetS in the population. Among the adolescent population, the MetS was evaluated using the age-adjusted NCEP-ATP III criteria by Pan & Pratt[58] and cluster analysis of MetS components was used by Ambrosini *et al.*[29].

Determining dietary patterns

The dietary patterns were assessed using both *a posteriori* (i.e. factor analysis and cluster analysis) and *a priori* analytical approach (index-based) methods.

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Dietary patterns based on a posteriori *analytical methods*. Cluster analysis and factor analysis were the most common *a posteriori* methods used to determine dietary patterns among different populations. Cluster analysis was used in six articles summarised in Table 1. In each of the studies two to five clusters were extracted. Each of the six studies had clusters representative of a healthy and an unhealthy dietary pattern. The findings of four studies[3,21,42,53] indicated a higher risk of the MetS among the populations within the unhealthier clusters compared with the healthier clusters. Seventeen studies used the factor analysis method to obtain the patterns prevalent among their study population and to examine the patterns' association with MetS prevalence or incidence indicated in Table 2. These studies have found two to six dietary patterns for their study population. The dietary patterns extracted among their study populations included 'Western/unhealthy' (n 13)[23,29,30,33,34,38,41,43,45,48,49,51,54], 'healthy' (n 10)[23,29,33,34,38,41,43,45,49,54] and 'traditional' (n 6)[30,32,38,45,48,51] dietary patterns. The dietary patterns observed in three of the studies were unclear[44,47,50]; therefore, they were not included in this classification (summarised at the bottom of Table 2). Based on these studies, the 'healthy' patterns were characterised by high intakes of vegetables, fruits, legumes, whole grains and fish. The unhealthy or the so-called 'Western' dietary pattern mainly constituted red/processed meat, refined grains, sweets, sugar-sweetened beverages and processed food, which resembled an unhealthy diet. The 'traditional' dietary patterns were specific for each country, for example, Lebanese, Korean or German 'traditional' dietary pattern. Further, ten studies, which had found a 'Western/unhealthy' dietary pattern among their populations, also found a direct association between this type of dietary pattern and MetS risk[23,29,30,33,34,38,43,48,49,51]. Four out of ten studies that found a 'healthy' dietary pattern among their population indicated an inverse association between the healthy dietary patterns and risk of the MetS[34,38,45,54]. Regarding the third most common pattern, the 'traditional' dietary pattern, mixed results showing both inverse[30,51] and direct[30,32] association between this type of diet and the MetS were obtained. Other dietary patterns similar to the 'Western' dietary pattern were found by the researchers, named as 'high glycaemic index and high-fat'[34], 'modern'[51], 'processed foods'[33] and 'fast food/desserts'[48] dietary patterns.

In the aforementioned studies the analyses were adjusted for common potential confounders including age, sex, socioeconomic status, energy intake, physical activity, BMI, smoking status, self-reported history or family history of chronic diseases and medication usage.

Dietary patterns based on a priori *analytical methods*. Sixteen studies[24–28,31,35–37,39,40,52,55–58] indicated in Table 3 used the *a priori* scoring method to investigate the relationship of the MetS and dietary patterns. These studies used different scoring methods to obtain an overall diet score for each individual in the population. The following score-based methods and indices were used: Alternative Healthy Eating Index-2006[27], DASH[27,40], Dietary Guidelines for Americans

Table 1. Summary of population-based studies that have investigated the relationship between dietary patterns, derived using the cluster analysis method from 2005 to 2014

Reference	Participant description (i.e. population size, age, study design, country)	Clustering methods, number of clusters: name of clusters	Confounders	Association between dietary pattern and MetS (significant results obtained after adjusting for confounders)
Sonnenberg *et al.* (2005)[3]	T: 1268; M: 0; F: 1268; 18–76 years; cross-sectional; USA	Wards, five clusters: (1) heart healthier; (2) lighter eating; (3) wine and moderate eating; (4) higher fat; (5) 'empty calorie'	Age, apoE status, smoking, PA and menopausal status	'Empty calorie' cluster contributes to significantly higher MetS prevalence than other clusters
Berg *et al.* (2008)[53]	T: 3412; M: 1610; F: 1802; 25–74 years; cross-sectional; Sweden	K-means, five clusters: (1) healthy; (2) sweet; (3) coffee; (4) traditional; (5) fast energy	Sex (stratified), age, smoking, PA and education	Compared with the 'healthy' cluster, the 'fast energy' cluster had a direct association with MetS prevalence
Leite *et al.* (2009)[42]	T: 1052; M: 527; F: 525; 42–74 years; cross-sectional; Italy	K-means, five clusters: (1) common; (2) animal products; (3) starch; (4) vegetal/fat; (5) vitamin/fibre	Age, sex, education, smoking, alcohol consumption and the degree of PA (BMI was also used to stratify results)	The 'starch' cluster had the highest and the 'vitamin/fibre' and 'vegetal/fat' clusters had the lowest MetS prevalence
Duffey *et al.* (2012)[21]	T: 3728; M/F; 18–30 years; 20-year FUP; longitudinal; USA	K-means, two clusters: (1) prudent; (2) Western	Age, sex, diet beverage consumption, examination centre, baseline weight, PA, EI, education, family structure and smoking status (diet beverage intake had an interaction effect)	The 'prudent' cluster had a lower risk of MetS compared with the 'Western' cluster
Kimokoti *et al.* (2012)[22]	T: 1146; M: 0; F: 1146; 25–77 years; 7-year FUP; longitudinal; USA	Wards, five clusters: (1) heart healthier; (2) lighter eating; (3) wine and moderate eating; (4) higher fat; (5) 'empty calorie'	Age, BMI, PA, smoking status, EI and menopausal status	No significant result was obtained
Song & Joung (2012)[46]	T: 4730; M: 1974; F: 2756; age ≥ 20 years; cross-sectional; Korea	K-means, three clusters: (1) traditional; (2) meat and alcohol; (3) Korean healthy	Age, sex, education, region, smoking and PA	No significant result was obtained

MetS, metabolic syndrome; T, total population size; M, male population size; F, female population size; PA, physical activity; FUP, follow-up period; EI, energy intake.

Table 2. Summary of population-based studiesthat have investigated the relationship between dietary patterns, derived using the factor analysis method from 2005 to 2014

Reference	Participant description (i.e. population size, age, study design, country)	Components/dietary patterns/factors observed	Confounders	Association between dietary pattern and MetS (significant results obtained after adjusting for confounders)
Esmaillzadeh *et al.* (2007)[38]	T: 486; M: 0; F: 486; 40–60 years; cross-sectional; Iran	Three dietary patterns: (1) healthy; (2) Western; (3) traditional	Age, smoking, PA, menopausal status, current oestrogen use, family history of diabetes/ stroke, EI and BMI	The 'healthy' dietary pattern had an inverse and 'Western' dietary pattern had a direct association with MetS prevalence
Panagiotakos *et al.* (2007)[34]	T: 3042; M: 1514; F: 1528; 18–89 years; cross-sectional; Greece	Six components: (1) healthful food: low-fat products; (2) high-glycaemic index and high-fat pattern; (3) pasta and bread; (4) dairy products and eggs; (5) sweets; (6) alcohol	Age, sex, physical inactivity, smoking, years of school, use of medication, BMI and income	The 'health-full food' pattern had an inverse association, while the 'high-glycaemic index and high-fat pattern' and the 'alcohol' pattern had a direct association with MetS prevalence
Lutsey *et al.* (2008)[23]	T: 9514; M: 4196; F: 5318; 45–64 years; 9-year FUP; longitudinal; USA	Two factors: (1) Western; (2) prudent	Age, sex, centre, education, race, smoking, pack-years and PA	The 'Western' dietary pattern had a direct association with MetS risk
Ambrosini *et al.* (2010)[29]	T: 1139; M: 593; F: 546; 14 years; cross-sectional; Australia	Two dietary patterns: (1) healthy pattern; (2) Western pattern	Sex, maternal education (mothers), being in a two-parent family, hours spent watching television, aerobic fitness and EI	The 'Western' dietary pattern was observed to have a direct association with MetS prevalence among females
Deshmukh-Taskar *et al.* (2009)[54]	T: 995; M: 388; F: 607; 19–39 years; cross-sectional; USA	Two dietary patterns: (1) Western; (2) prudent	Age, EI, sex, ethnicity, SES, marital status, PA, smoking, alcohol consumption and BMI	The 'prudent' dietary pattern had an inverse association with MetS prevalence
DiBello *et al.* (2009)[51]	T: 785; M/F; age ≥ 18 years; cross-sectional; Samoa	Three factors: (1) neo-traditional pattern; (2) modern pattern; (3) meat and coconut products	Age, sex, material lifestyle score, current smoking status, PA, EI, diabetes medication use and hypertension medication use	The 'neo-traditional' dietary pattern had an inverse and 'modern' dietary pattern had a direct association with MetS prevalence
Denova-Gutiérrez *et al.* (2010)[49]	T: 5240; M: 1489; F: 3751; 20–70 years; cross-sectional; Mexico	Three dietary patterns: (1) prudent; (2) Western; (3) high protein/fat	Age, sex, PA, place of residence, weight changes, cigarette smoking, oestrogen use, menopausal status and EI	The 'Western' dietary patterns had a direct association with MetS prevalence
Cho *et al.* (2011)[45]	T: 4984; M: 0; F: 4984; 30–79 years; cross-sectional; Korea	Three factors: (1) Western; (2) healthy; (3) traditional	Age	The 'healthy' dietary patterns had an inverse association with MetS prevalence
Heidemann *et al.* (2011)[33]	T: 4025; M: 1761; F: 2264; 18–79 years; cross-sectional; Germany	Two dietary patterns: (1) processed food pattern; (2) health-conscious pattern	Age, sex, EI, SES, sport activity, smoking status	The 'processed food pattern' had a direct association with MetS prevalence
Akter *et al.* (2013)[43]	T: 460; M: 284; F: 176; 21–67 years; cross-sectional; Japan	Three factors: (1) healthy Japanese dietary; (2) animal food; (3) Westernised breakfast	Age, sex, workplace, marital status, job position, occupational physical activity, current smoking, and non-occupational PA	The 'Westernised breakfast' pattern had a direct association with MetS prevalence
He *et al.* (2013)[30]	T: 20 827; M: 9936; F: 10 891; 45–69 years; cross-sectional; China	Three patterns: (1) yellow earth; (2) green water; (3) Western/new affluence	Age, sex, rural/urban, family income, educational level, current smoking, drinking, PA (had interaction effect), cooking salt/ salted vegetable consumption, EI, family history of hypertension, family history of diabetes and BMI	Compared with the 'green water' pattern, the 'yellow earth' and the 'Western/affluence' had a direct association with MetS prevalence
Naja *et al.* (2013)[48]	T: 323; M: 160; F: 163; age ≥ 18 years; cross-sectional; Lebanon	Three patterns: (1) fast food/dessert; (2) traditional Lebanese; (3) high protein	Age, sex, marital status, education, crowding index, PA and smoking	The 'fast food/dessert' dietary pattern had a direct association with MetS prevalence
Barbaresko *et al.* (2014)[32]	T: 905; M: 517; F: 390; 25–82 years; cross-sectional; Germany	Two dietary patterns: (1) German traditional; (2) name not indicated	Age, sex, education, smoking, PA, total energy and study cohort	The 'German traditional' dietary pattern had a direct association with MetS prevalence
Buscemi *et al.* (2014)[41]	T: 477; M: 167; F: 310; age ≥ 18 years; cross-sectional; Italy	Three patterns: (1) unhealthy; (2) healthy; (3) intermediate	Age, sex, dietary cluster and PA	No significant association observed
Studies not included in the results and discussion				
Kim & Jo (2011)[47]	T: 9850; M/F; age ≥ 19 years; cross-sectional; Korea	Four dietary patterns: (1) white rice and kimchi pattern; (2) meat and alcohol pattern; (3) high-fat, sweets, and coffee pattern; (4) grains, vegetables, and fish pattern	Age, sex, BMI, EI, alcohol intake, smoking status, and PA	The 'grains, vegetables, and fish' dietary pattern had an inverse association with MetS prevalence
Fonseca *et al.* (2012)[50]	T: 2167; M: 837; F: 1330; age > 64 years; cross-sectional; Portugal	Four patterns: (1) for both sexes: healthy; (2) for females: low fruit and vegetables, for males: fish; (3) for both sexes: red meat and alcohol; (4) for females: in transition to fast-food, for males: intermediate	Age, EI, education, BMI, PA, smoking, alcohol consumption and menopausal status (in women) (sex was stratified)	Women with the 'red meat and alcohol' dietary pattern had the higher MetS prevalence compared with the women with 'healthy' dietary pattern
Hong *et al.* (2012)[44]	T: 406; M: 264; F: 142; 22–78 years; cross-sectional; Korea	Four patterns: (1) Korean traditional; (2) alcohol and meats; (3) sweets and fast foods; (4) fruit and dairy products	Age, sex, medications, smoking status, physical activity, and BMI	The 'Korean traditional' dietary pattern had a direct and the 'Fruit and Dairy' dietary pattern had an inverse association with MetS prevalence

MetS, metabolic syndrome; T, total population size; M, male population size; F, female population size; PA, physical activity; EI, energy intake; FUP, follow-up period; SES, socio-economic status.

Table 3. Summary of population-based studies that have investigated the relationship between *a priori* dietary patterns and the metabolic syndrome from 2005 to 2014

Reference	Participant description (i.e. population size, age, study design, country)	Name, basis, number of components, score ranges of *a priori* approach	Confounders	Association found between dietary pattern and MetS (significant results indicated after adjusting for confounders)
Mediterranean diet-based indices				
Álvarez León *et al.* (2006)[52]	T: 578; M: 249; F: 329; age > 18 years; cross-sectional; Spain	Total Mediterranean score; based on adherence to the Mediterranean diet; ten components; score range from 10 to 30 points	Sex, age, educational level, PA, BMI, diet in the past 12 months, EI and tobacco consumption	No significant result was obtained
Thanopoulou *et al.* (2006)[28]	T: 1833; M: 916; F: 917; 20–74 years; cross-sectional; five Mediterranean countries	Traditional Mediterranean diet; based on the adherence to the traditional Mediterranean diet; nine components; score ≥ 5; scores range from 0 to 9 points[83]	Age, sex and total energy	No significant result was obtained
Rumawas *et al.* (2009)[24]	T: 1918; M: 798; F: 1120; mean age 54 years; 7-year FUP; longitudinal; USA	Mediterranean-style dietary pattern score; based on the Mediterranean; diet pyramid; thirteen components; score ranges from 0 to 100 points	Age, sex, EI, smoking dose, BMI, and change in BMI among participants without MetS at the baseline	Inverse
Tzima *et al.* (2009)[35]	T: 3042; M: 1514; F: 1528; 18–89 years; cross-sectional; Greece	MedDiet Score[84]; based on the Mediterranean diet; sixteen components; score ranges from 0 to 55 points	Age, sex, BMI, smoking habits, PA status	Inverse
Gouveri *et al.* (2011)[36]	T: 2074; M: 900; F: 1174; age > 18 years; cross-sectional; Greece	MedDiet; based on the traditional Mediterranean diet; eleven components; score ranges from 0 to 55	Age, sex, smoking, light PA, serum levels of LDL-cholesterol and γ-glutamyl transferase, CVD, diabetes mellitus, and hyperlipidaemia and/or family history of hypertension	Inverse
Kesse-Guyot *et al.* (2013)[25]	T: 3232; M: 2105; F: 1127; adult; 6-year FUP; longitudinal; France	Mediterranean dietary patterns; (1) MDS: included ten components and score ranges from 0 to 9 points; (2) MED score: included twelve components and score ranges from 0 to 12 points; (3) MSDPS: included thirteen components and score ranges from 0 to 100 points	Age, sex, total daily energy, number of 24 h recall dietary records, baseline smoking status, baseline PA, education level, treatment allocation group and baseline BMI	(1) MDS: inverse (stronger association with MetS compared with MED); (2) MED: inverse; (3) MSDPS: inverse (borderline significance)
Yang *et al.* (2014)[55]	T: 780; M: 780; F: 0; age ≥ 18 years; cross-sectional; USA	MMDS; based on the Mediterranean diet; score ranges from 0 to 42 points	Age and PA	Inverse
HEI-1995, DASH, DGAI and other indices				
Fogli-Cawley *et al.* (2007)[56]	T: 3177; M: 1493; F: 1684; 26–82 years; cross-sectional; USA	DGAI*; based on 2005 Dietary Guidelines for Americans; includes twenty components	Age (stratified with cut-off of 55 years), sex, current smoking, current multivitamin supplement use, PA, and EI	(1) If participants with need of treatment were excluded: inverse; (2) if age < 55 years: inverse
Pan & Pratt (2008)[58]	T: 4450; M: 2260; F: 2190; 12–19 years; cross-sectional; USA	HEI-1995[85]†; based on the Food Guide Pyramid; ten components; score ranges from 0 to 100 points	Age, sex, ethnicity, poverty status, BMI and PA	Overall HEI-1995, inverse (not observed significant association with odds in logistic regression)
Gregory *et al.* (2009)[37]	T: 1220; M: 469; F: 751; 25–42 years; cross-sectional; Guatemala	Recommended Food Score; Not Recommended Food Score; Food Variety Score; and the Dietary Quality Index-International	Age, smoking, physical activity level and residence	No significant result was obtained
Hosseini-Esfahani *et al.* (2010)[39]	T: 2504; M: 1120; F: 1384; 19–70 years; cross-sectional; Iran	DGAI 2005; eleven items are related to the energy-specific 'food group recommendation' and eight items assess the 'healthy choice recommendation', the alcohol consumption item was excluded	Age, sex, EI, smoking status and PA	Inverse
Kouki *et al.* (2012)[31]	T: 1334; M: 663; F: 671; 57–58 years; cross-sectional; Finland	Five-grade Diet Score; scored based on achieving adherence to the four following nutritional recommendations: ≥400 g vegetables per d, ≥2 servings of fish per week, ≥14 g fibre per 4184 kJ (1000 kcal), and <10 % energy of SFA	Age, sex, smoking, alcohol consumption, education, prevalent diseases, cognitive function, depression, as well as medications and maximal O_2 uptake tertiles	Inverse
Saneei *et al.* (2015)[40]	T: 420; M: 0; F: 420; age > 30 years; cross-sectional; Iran	DASH‡; based on the DASH diet; eight components; score ranges from 8 to 40 points	Age, EI, current oral contraceptive use, current corticosteroid use, PA, marital status, menopausal status, socio-economic status and BMI	Inverse
Vegetarian dietary patterns				
Rizzo *et al.* (2011)[57]	T: 773; M/F; 30–94 years; cross-sectional; USA	Vegetarian dietary pattern assessment with the following classifications: (1) vegetarian: intake of meat, fish or poultry less than once per month; (2) semi-vegetarian: intake of any amount of fish, but less than once per month of other meat; (3) non-vegetarian: intake of more than once per month of red meat or poultry and a total of more than once per week of all meats	Age, sex, ethnicity, smoking, alcohol intake, PA and EI	Vegetarians had lower MetS prevalence compared with non-vegetarians
Shang *et al.* (2011)[26]	T: 93 209; M/F; 3·75 years FUP; longitudinal; Taiwan	Classified participants based on meat, fish, dairy product and egg consumption to the following four dietary patterns: (1) non-vegetarians; (2) pesco-vegetarians; (3) lacto-vegetarians; (4) vegans	Sex, age, education status, smoking status, drinking status, physical activity at work and leisure	The risk of MetS was higher for vegans than for non-vegetarians, pesco-vegetarians and lacto-vegetarians

Table 3 *Continued*

Reference	Participant description (i.e. population size, age, study design, country)	Name, basis, number of components, score ranges of *a priori* approach	Confounders	Association found between dietary pattern and MetS (significant results indicated after adjusting for confounders)
Pimenta *et al.* (2015)[27]	T: 6851; M/F; mean age: 30 years; 8·3 years FUP; longitudinal; Spain	(1) Pro-vegetarian diet§, based on a diet which constitutes plant rather than animal origin; seven plant- and five animal-origin food groups were considered, scores ranged from 12 to 60 points; (2) DASH score: based on adherence to DASH, includes eight components, scores range from eight to 40 points; (3–8) six Mediterranean diet-based score methods including the following: the MDS, MMDS, MAI, MDQI, MFP and MED; (9) DQI; (10) HEI-1995; (11) AHEI-2006; (12) DGAI; (13) DII	Age, sex, smoking status, alcohol consumption, PA, time spent viewing television, EI, use of special diets, snacking between main meals, changes in weight over the last 5 years before the study and BMI	(1) Inverse; (2) stratified for alcohol intake: only if low intake of alcohol: inverse, for dietary patterns; 3–13, no significant result was obtained

MetS, metabolic syndrome; T, total population size; M, male population size; F, female population size; PA, physical activity; EI, energy intake; FUP, follow-up period; MDS, Mediterranean Diet Score; MED, Mediterranean Score; MSDPS, Mediterranean Style Dietary Pattern Score; MMDS, Modified Mediterranean Diet Score; HEI-1995, Healthy Eating Index-1995; DASH, Dietary Approaches to Stop Hypertension; DGAI, Dietary Guidelines for Americans Index; MAI, Mediterranean Adequacy Index; MDQI, Mediterranean Diet Quality Index; MFP, Mediterranean Food Pattern; DQI, Diet Quality Index-International; AHEI-2006, Alternative Healthy Eating Index-2006; DII, Dietary Inflammatory Index.

* Another dietary index developed to assess the dietary pattern of individual in epidemiological studies is the Dietary Guidelines for Americans Index. This dietary index is developed based on the adherence to the Dietary Guidelines for Americans. The purpose of the Dietary Guidelines for Americans is to reduce the risk of chronic conditions such as CVD. This index includes twenty categories within two main components. The first component is related to the recommendations regarding intake of energy-specific food groups, which includes eleven categories. These items include fruits; five vegetable subgroups; a variety of vegetables; grains; milk and milk products; meat and legumes; and discretionary energy. The second component is the healthy choice or nutrient intake recommendations that include nine categories. The items are as follows: fibre intake; percentage of grains that are whole grain; Na intake; alcohol consumption; five recommendations related to fat and cholesterol intake, including, total fat and saturated fat as a percentage of energy, low-fat milk and meat choices, *trans*-fat intake and cholesterol intake[56].

† One dietary index developed based on the adherence to the Food Guide Pyramid is the Healthy Eating Index. This index includes the sum of scores from the following ten components: grains, vegetables, fruits, milk, meat or meat alternatives, total fat intake, saturated fat, cholesterol, Na and diet variety. The scores range from 0 to 100, with higher scores indicating a better diet quality[85].

‡ The Dietary Approaches to Stop Hypertension (DASH) score is based on the adherence to the DASH diet plan developed to control specific chronic conditions including hypertension. The scoring method to evaluate the adherence to DASH was based on the consumption of eight foods as adequate or inadequate foods. The eight components were as follows: high intake of fruits; vegetables; nuts and legumes; low-fat dairy products; whole grains and low intake of Na, sweetened beverages, and red and processed meats. The sum of the scores ranged from 8 to 40 points, with the higher scores indicating a greater adherence. The DASH diet is mainly investigated in randomised controlled studies[86,87].

§ The Pro-Vegetarian Diet is a diet based on plants rather than food derived from animals. Seven plant- and five animal-origin food groups were considered. The score of this diet ranges from 12 to 60, higher scores indicating better adherence to this diet. The results showed an inverse association between Pro-Vegetarian Diet scores and MetS incidence[27].

Index[27,39,56], Dietary Inflammatory Index[27], Diet Quality Index-International[27,37], Healthy Eating Index-1995[58], MedDiet score[35,36], Mediterranean Adequacy Index[27], Mediterranean Diet Quality Index[27], Mediterranean Diet Score[25,27], Mediterranean Food Pattern[27], Mediterranean Score[25], Mediterranean-Style Dietary Pattern Score[25], Modified Mediterranean Diet Score[27,55], Pro-Vegetarian Diet[27], Recommended Food Score[37], Not Recommended Food Score[37], Total Mediterranean score[52], Traditional Mediterranean diet score[28] and other vegetarian dietary patterns[26,57].

The studies that used the Healthy Eating Index-1995, Dietary Guidelines for Americans Index or indices developed based on the adherence to a vegetarian diet for evaluating their populations' diet quality obtained mixed results, indicating a negative association or no significant association between these diets and risk of the MetS (Table 3). However, the two studies using the DASH diet score indicated the higher the DASH score the lower the risk of the MetS was for their population[27,40].

Adherence to the Mediterranean diet or pyramid has been evaluated by eight studies[24,25,27,28,35,36,52,55]. In these studies, the Mediterranean dietary pattern consisted of high intakes of fruits, vegetables, cereals, legumes, fish, nuts, olives and a high ratio of monounsaturated to saturated fats, moderate to low intake of alcohol/wine, dairy products and meat. Five of these studies found that the higher the adherences to the Mediterranean diet the lower the risk of the MetS would be[24,25,35,36,55]. The remaining studies did not find any significant results[27,28,52].

Discussion

Based on the search strategy of the present review, thirty-nine population-based studies were identified that investigated the association of the MetS and dietary patterns. Findings of the present review showed that population-based studies have been conducted in different countries especially in European and North American countries, and on adult populations of both sexes. These studies tended to use the factor analysis method and also the *a priori* dietary approaches, such as the Mediterranean dietary pattern. Based on this review of population-based studies, the Mediterranean diet and the 'Western' dietary pattern seemed to be the two extremes of the MetS and diet association continuum.

The relationship between MetS components and CVD is established from the early stages of life and remains until adulthood. Therefore, it is essential to identify and investigate the presence of the MetS in children and adolescents[60]. Based on the findings of this review study a gap exists in the investigation of the MetS among adolescents and children. This gap is a consequence of recommendations by authoritative bodies to investigate the MetS only among individuals above the age of 10 years; as well, there remains an inconsistency in MetS definitions used by researchers working with children and adolescents[61–63]. The methodological approach in determining the dietary pattern of a population, whether *a priori* or *a posteriori*, was chosen based on the research question. However,

researchers did not explain the reason behind the choice of methodological approach in *a posteriori* methods. Those who used the *a priori* methods indicated that assessing adherence to the specific diet through its relevant index was the reasoning behind their choice.

The a posteriori analytical methods

Among the aforementioned possible *a posteriori* approaches, factor analysis and cluster analysis were the most common methods used in the epidemiological studies included in this review and similarly indicated by Newby & Tucker[64]. In factor analysis, the dietary patterns are determined by statistically evaluating the correlation between the entering variables, which generate discrete factors from similar input variables[65], while cluster analysis is a method in which individuals with similar dietary characteristics are aggregated into one categorical cluster[4]. These methods extract the actual dietary patterns of the populations. However, the disadvantage of these two commonly used methods is their subjectivity and that they do not account for the disease risk[10]. An approach that derives dietary patterns based on disease risk is the reduced ranked regression method, which has been introduced to nutritional epidemiology by Hoffmann *et al.*[10]. This method is mainly based on the scientific evidence of disease-specific response variables, which may be the components of a disease or nutrients related to a disease[10]. To our knowledge, three studies[32,66,67] have used the reduced ranked regression method, which focuses on nutrients or MetS components as dependent variables to investigate the association between the MetS and diet. Therefore, based on the aim, to have real-world dietary patterns or dietary patterns related to a specific disease risk, researchers have to choose one of these empirical analytical methods[10]. Researchers should consider potential limitations when applying *a posteriori* methods including the limited reproducibility due to several decision-making points and the limited data available regarding the validity of this approach in epidemiological studies[68].

In nearly all studies, which have used factor analysis or cluster analysis, both a 'Western/unhealthy' and a 'healthy/prudent' dietary pattern were observed to be prevalent among their study populations. As for the 'Western/unhealthy' dietary pattern and similar dietary patterns such as 'energy dense', 'fast energy', 'empty calorie' and 'modern', these patterns were shown to have a direct association with MetS status in most of the studies. Even though in some of the studies indicated in Tables 1 and 2, researchers adjusted for BMI, weight change, energy intake, physical activity and smoking status as potential confounders, the association remained singificant. This suggests that the effect of the 'Western/unhealthy' dietary pattern on MetS status is beyond the effect of anthropometric and other lifestyle factors as similarly indicated by Calton *et al.*[15]. Previous evidence suggests that high intakes of refined grains, sugar, saturated fats and low intake of fruits and vegetables increase the risk of the MetS by increasing inflammation[69]. This can be one explanation for the associations observed among dietary patterns and the MetS. Further, findings of only four of these studies have indicated an inverse association between the 'healthy' dietary pattern and the MetS.

The a priori analytical methods

The overall aim of the *a priori* approach is to compare and classify the population into categories based on their adherence to recommendations or well-known healthy diets[70]. This score-based method is used to indicate the characteristics of the overall diet[11,12]. While this method is more reproducible compared with the *a posteriori* methods[68], the disadvantage of using recommendations to develop an index of diet quality is that the index score is the sum of the points allocated to each of the components of the index. The inter-correlation of the score components with one another may have not been proven. Hence, a total score is not representative of the overall effect of the diet[10]. Studies included in this review that have used the Healthy Eating Index-1995, Dietary Guidelines for Americans Index and the vegetarian dietary patterns observed mixed results, which indicate the need for further research.

In addition to the recommendation-based indices, dietary patterns such as the Mediterranean diet, initially identified via *a posteriori* methods, have been used to develop indices with the aim of evaluating the adherence to these healthy-known dietary patterns[70,71]. Eight studies included here (Table 3) have used different indices developed based on the Mediterranean diet. Five of these studies have indicated the higher the adherence to this diet the lower risk of the MetS. This may be evidence to the reproducibility and validity of this diet as a beneficial diet for preventing the MetS. Similar to the present results, the preventative impact of the Mediterranean diet on the MetS has been proven in interventional studies[72]. As well, a systematic review study conducted on observational and RCT studies has concluded that the Mediterranean diet reduces the risk of the MetS[13]. This nutrient-dense diet not only targets weight loss, but also reduces the levels of inflammatory biomarkers and atherogenic lipoproteins due to its high phytonutrient and beneficial fatty acid contents[73]. More studies have observed the protective effect of the Mediterranean diet (five out of eight) compared with studies that evaluated the 'prudent/healthy' dietary pattern (four out of ten). This may be due to the emphasis on higher intakes of nuts, olive/olive oil, monounsaturated:saturated ratio and moderate intakes of alcohol/wine in the Mediterranean diet compared with the 'prudent/healthy' dietary pattern. A similar association between DASH and the MetS was observed in two studies[27,40]. An RCT study has conclusively demonstrated that the DASH diet has an improving impact on MetS status compared with not only a normal control diet but also a weight-reducing diet[74]. Although the Mediterranean diet seems to have a higher fat content compared with the DASH diet[15], the promising results from the included population-based studies indicate that both diets contribute to a lower risk of MetS prevalence and incidence.

The Mediterranean and the 'Western' dietary patterns

Based on this review of the population-based studies, the Mediterranean diet and the 'Western' dietary pattern seem to be

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the two most common extracted dietary patterns having a significant association with the MetS. The different effect of the two diets on the MetS reflects the opposite impact of their components on the MetS. Based on these studies, the Mediterranean diet was defined as a diet high in whole grains, fruits and vegetables, fish, legumes, nuts, monounsaturated fats and olive oil and moderate to low intake of meat, dairy products and alcohol. However, the 'Western' dietary pattern is characterised by high intakes of red/processed meat, fast food, refined grains/cereals, sugar-sweetened beverages, eggs, sweets/desserts and low intake of fruit and vegetables, and dairy products. While the Mediterranean diet consists of high intakes of fibre and whole grains, the 'Western' dietary pattern constitutes of high intakes of refined grains. The effect of whole grains and high fibre on the waist circumference component of the MetS has been observed in epidemiological studies. The inverse association between the MetS and whole grains intake may be due to the impact of whole grain consumption on the components of the MetS such as HDL-cholesterol[75]. On the other hand, intake of refined grains contributes to a high glycaemic index, which could increase the risk of the MetS. Findings from a study conducted among older adults indicated an inverse and direct association for whole and refined grains, respectively[76].

The Mediterranean diet has a moderate to low intake of red meat, while in the 'Western' dietary pattern a high intake of red/processed meats is observed. The association of MetS status and meat has been evaluated in a few studies[23,77,78]. Regarding red meat, most studies have yielded a direct association between the MetS and meat intake. Results of the Atherosclerosis Risk in Communities Study indicated that meat products such as hamburgers, hotdogs and processed meats increase the risk of the MetS[23]. The increasing risk of the MetS with higher meat consumption could be due to the high saturated fat content of meat and its association with MetS components such as blood pressure and abdominal obesity[23].

The Mediterranean diet is rich in fruits and vegetables while the 'Western' dietary pattern is deficient in these foods. The relationship between vegetables and fruit intake and the MetS has been assessed in a few studies. A cross-sectional study[79] among adult women in Tehran revealed an inverse association. However, in the Atherosclerosis Risk in Communities Study[23] and a cross-sectional study[80] based on Canadian Health Measures Survey Cycle 1 data, no significant association was observed between fruit and vegetable intake and MetS status. The expected reducing impact of fruit and vegetables on the MetS is due to these foods optimising the effect on MetS components such as blood pressure[23,81] or fasting plasma glucose[15]. Further research is required in this area to reveal the impact of this food group on the MetS, which may have been obscured due to including foods such as potatoes within the vegetables group.

Based on this review study, twelve studies[3,21–23,29,33,34,41,49-51,54] have found a 'Western/unhealthy' dietary pattern prevalent in Westernised countries of the world. None of these studies indicated a high intake of alcohol as a characterising factor of the 'Western/unhealthy' dietary pattern. However, one of these studies[54] has considered alcohol consumption as a potential confounding factor in the statistical analysis. Four studies among Western populations[3,22,34,50] have extracted a separate dietary pattern which is characterised by high intakes of alcohol. Two of these studies have indicated a direct association between an alcohol dietary pattern and the MetS[34,50].

The other components of the Mediterranean diet including olive/olive oil, moderate alcohol/red wine, nuts, legumes and fish also contribute to a high MUFA and PUFA and antioxidant profile, which results in lowering the risk for chronic inflammatory conditions such as the MetS[82]. For example, virgin olive oil has a high monounsaturated fat and polyphenol profile, which has an optimal effect on blood lipids, hypertension and insulin sensitivity. All these effects contribute to a lower risk of the MetS[82].

The overall impact of the Mediterranean diet on the MetS is related to the impact on each of the MetS components, the anti-inflammatory effect and the impact on insulin resistance which is known to have a significant role in the development of the MetS[82]. The complexity of this syndrome with multiple components requires a diet that prevents and/or controls the risk such as the Mediterranean diet that affects all the components of the MetS in an optimising direction[81]. However, the components of the 'Western' diet provoke the MetS components. Thus, in view of the beneficial effects of the Mediterranean diet on the MetS, promoting this dietary pattern or its most beneficial components relevant to different populations' cultural practices may be an effective preventive strategy.

There are limitations to be considered due to the nature of a review study. First, only English-language studies have been included. However, the included articles are from a variety of countries where the official language is not necessarily English. In addition, studies published between 2005 and 2014 have been included in this review, while there are earlier review papers that include studies published before 2005.

Conclusion

The high worldwide burden of CVD and diabetes as the most common cause of mortality and morbidity has led many researchers across the globe to investigate the link between the MetS and diet as a modifiable factor. Findings of studies from twenty-three countries indicate that 'Western', Mediterranean, 'healthy' and 'traditional' dietary patterns are common diets among adult populations across the globe. Using different MetS criteria, the studies included in this review concluded an association between these dietary patterns and MetS status during adulthood. Since no unified definition of the MetS exists for adolescence, it creates challenges in investigating the association between dietary patterns and the MetS in this age group.

Findings of the present review suggest that the methods used to determine the dietary pattern of a population should be chosen based on the purpose of research. As the MetS consists of many components, investigation of a dietary pattern is beneficial in understanding the overall effect of diet rather than individual nutrients or food items on the MetS. Our scoping review revealed support for diets based on the Mediterranean diet and for the avoidance of the 'Western' diet in preventing the MetS, based on population-based studies which are in

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agreement with RCT. Promoting the Mediterranean components among populations where the Western dietary pattern is prevalent could be considered.

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Supplementary material

For supplementary material/s referred to in this article, please visit http://dx.doi.org/doi:10.1017/S095442241600007X

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