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DIABETOLOGY & METABOLIC SYNDROME

REVIEW Open Access

Fish consumption and its possible preventive role on the development and prevalence of metabolic syndrome - a systematic review

Christine Tørris[1,2*], Marianne Molin[2] and Milada Cvancarova Småstuen[1,2]

Abstract

Metabolic syndrome (MetS) has a huge impact on public health, and today lifestyle interventions remain the primary mode for MetS therapy. It is therefore important to elucidate the possible preventive effects of diet and foods, and their MetS-related health implications. To examine how fish consumption affects the development and prevalence of MetS, we systematically reviewed cross-sectional, prospective cohort, and intervention studies conducted among adults (humans) and, reporting consumption of fish or seafood as being related to MetS (prevalence or incidence), where MetS was defined via an established definition. The literature search in PubMed identified 502 citations, and after screening, 49 full-text articles were retrieved and assessed for eligibility. After excluding duplicates and those not meeting the inclusion criteria, seven studies from Croatia, Finland, France, Iceland, Iran, Korea, and US were included. Four studies (one follow-up and three cross-sectional) found associations between fish consumption and MetS (three among men, and one among women), suggesting that fish consumption may prevent or improve metabolic health and have a protective role in MetS prevention. This protective role might be related to gender, and men may benefit more from the consumption of fish. However, lack of controlling for potential confounders may also inflict the results. Additional research is required to further explore fish consumption and its potential role in improving or reversing MetS and its components.

Keywords: Metabolic syndrome, Insulin resistance, Diet, Fish intake, Seafood, Consumption of fish, Systematic review

Introduction

Metabolic syndrome (MetS) is a cluster of risk factors for cardiovascular disease (CVD) and diabetes mellitus type 2 (DM2) with metabolic abnormalities including abdominal obesity, dyslipidaemia, hyperglycaemia, and hypertension [1,2]. Several definitions and diagnostic criteria for MetS have been proposed, the latest by the new Joint Interim Societies (JIS) [2]. MetS has been associated with a doubling of CVD risk as well as a 5-fold increased risk of DM2 [3]. The syndrome affects public health, and the increased risk of morbidity and mortality is profound [4].

Consumption of fish has been identified as a protective factor against several types of disease. Over the past decades a considerable amount of literature has been published on CVD and the benefits of fish consumption [5,6]. Today, lifestyle interventions remain the primary therapy for MetS, and it is important to emphasize the role of diet and food, such as fish, and their possible MetS-related health implications. So far, many studies have focused on single components in marine nutrients, such as n-3 fatty acids [7,8]. However, few studies have investigated associations between fish consumption and MetS development and prevalence. This study primarily aims to examine how the consumption of fish affects the development and prevalence of MetS. This research question was explored by reviewing cross-sectional, prospective cohort, and intervention studies conducted among adults (humans) and reporting consumption of fish or seafood as being related to MetS (prevalence or incidence), where MetS was defined via an established definition.

* Correspondence: christine.torris@hioa.no
[1]Oslo and Akershus University College, Oslo, Norway
[2]Institute of Basic Medical Sciences, University of Oslo, Blindern, Oslo, Norway

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Methods

Literature search was performed in PubMed to identify published studies examining associations between consumption of fish among humans as the exposure, versus the development and prevalence of MetS as the outcome. Combined search terms were *fish, seafood, intake,* and *consumption* as exposure search terms, and *metabolic syndrome* or *insulin resistance* as outcome search terms. The last search was performed June 1st 2014.

Potential abstracts and full-text articles were screened before removing duplicates. Full-text articles were assessed for eligibility, and seven studies were included in this review after exclusion. The selection process is illustrated via a flow diagram (Figure 1).

All cross-sectional, prospective cohort, and intervention studies considered for inclusion were conducted among adults (humans), and reported consumption of fish or seafood related to MetS (prevalence or incidence), where MetS was defined via an established definition. Prospective cohort studies were considered eligible for inclusion if they had at least one year of follow-up and involved general populations. Insulin resistance syndrome (IRS) was accepted as an outcome factor and considered for inclusion when using the same definition as in MetS. Abstracts, letters, or reviews were not included, but were inspected for additional references that meet the inclusion criteria. Reference lists of the included studies and relevant published reviews were examined to identify additional papers for possible inclusion.

The search was restricted to papers written in English, and animal studies were excluded. Full-text of the article was retrieved whenever there was uncertainty about the study's match with the inclusion criteria. The included studies were assessed according to the quality of the study design and methods, measurements of MetS and fish consumption, and the statistical analysis. The review procedure was carried out in accordance with the PRISMA statement for review reporting [9], and a protocol of the study selection was made.

The data collected from the studies included: reference, country where the study was performed, design, aim, participants' age and sex, (baseline age and duration of follow-up for prospective studies), sample size, methods of measurement, variables adjusted for in the analysis, multivariate adjusted OR with a 95% CI for the lowest versus the highest consumption of fish, and MetS incidence or prevalence.

Results

The literature search identified 502 citations, and after screening titles and abstracts, 49 full-text articles were retrieved and assessed for eligibility. Finally, seven studies investigating associations between fish consumption and MetS were included in this review. The criteria for diagnosing MetS for the included studies are shown in Table 1, and study characteristics are provided in Table 2. The included studies comprise of one intervention study from Iceland [10], one follow-up study from Korea [11],

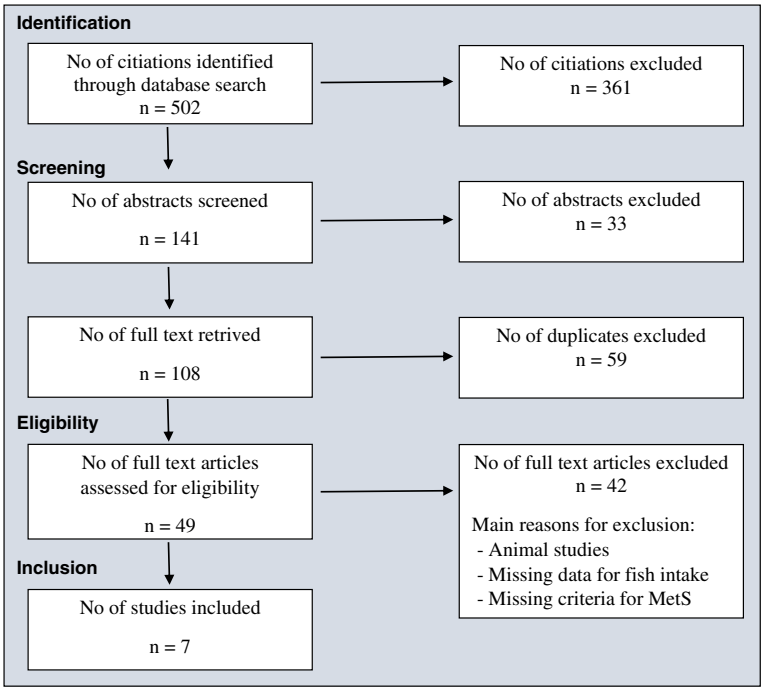

Figure 1 Flow of studies through the different phases of this systematic review.

Table 1 Different criteria for diagnosing metabolic syndrome (MetS) used in studies included in this review

	Criteria	Study	Men	Women
Waist	IDF [22]	Pasalic et al., 2011 [14]	≥ 94 cm	≥ 80 cm
	IDF [17]	Ramel et al., 2009 [10]		
	JIS [2]	Zaribaf et al., 2014 [16]		
	ATP III [20]	Kouki et al., 2011 [12]	> 102 cm	> 88 cm
	ATP III [21]	Lai et al., 2013 [13]		
	ATP III [20]	Ruidavets et al., 2007 [15]		
	Alternative [19]	Baik et al., 2010 [11]	≥ 85 cm	≥ 80 cm
S-HDL cholesterol	ATP III [18]	Baik et al., 2010 [11]	< 1.0 mmol/L (40 mg/dL)	< 1.3 mmol/L (50 mg/dL)
	ATP III [20]	Kouki et al., 2011 [12]		
	ATP III [21]	Lai et al., 2013 [13]		
	IDF [22]	Pasalic et al., 2011 [14]		
	IDF [17]	Ramel et al., 2009 [10]		
	ATP III [20]	Ruidavets et al., 2007 [15]		
	JIS [2]	Zaribaf et al., 2014 [16]		
	ATP III [18]	Baik et al., 2010 [11]		
	ATP III [20]	Kouki et al., 2011 [12]		
	ATP III [21]	Lai et al., 2013 [13]		
S-triglyceride	IDF [22]	Pasalic et al., 2011 [14]	> 1.7 mmol/L (150 mg/dL)	
	IDF [17]	Ramel et al., 2009 [10]		
	ATP III [20]	Ruidavets et al., 2007 [15]		
	JIS [2]	Zaribaf et al., 2014 [16]		
	ATP III [18]	Baik et al., 2010 [11]		
	ATP III [20]	Kouki et al., 2011 [12]		
	ATP III [21]	Lai et al., 2013 [13]		
Blood pressure	IDF [22]	Pasalic et al., 2011 [14]	SBP ≥130 mm Hg	
	IDF [17]	Ramel et al., 2009 [10]	DBP ≥85 mm Hg	
	ATP III [20]	Ruidavets et al., 2007 [15]		
	JIS [2]	Zaribaf et al., 2014 [16]		
	ATP III [18]	Baik et al., 2010 [11]	≥ 5.6 mmol/ L (100 mg/dL)	
Fasting S-glucose	IDF [22]	Pasalic et al., 2011 [14]		
	IDF [17]	Ramel et al., 2009 [10]		
	JIS [2]	Zaribaf et al., 2014 [16]		
	ATP III [20]	Kouki et al., 2011 [12]	≥ 6.1 mmol/l (110 mg/dL)	
	ATP III [21]	Lai et al., 2013 [13]		
	ATP III [20]	Ruidavets et al., 2007 [15]		

ATP III: Adult Treatment Panel III; the presence of three criteria must be fulfilled to diagnose MetS. IDF: International Diabetes Foundation; the criteria of waist (population specific) and two of the other criteria must be fulfilled to diagnose MetS.
JIS: Joint Interim Statement; the criteria of waist (population specific) and two of the other criteria must be fulfilled to diagnose MetS.
SBP: Systolic blood pressure. DBP: Diastolic blood pressure.

and five cross-sectional studies [12-16]- three conducted in Europe (Finland [12], Croatia [14], France [15]), one in USA [13], and one in Iran [16].

Intervention studies

The intervention study was carried out in Iceland [10], as part of the Icelandic arm of the SEAFOODplus YOUNG study. The aim was to investigate whether cod consumption increased weight loss and improved cardiovascular (CV) risk factors during an eight-week energy-restricted diet (−30%). Overweight/obese, but otherwise healthy young adults aged 20–40 years were recruited through advertisements (n = 126). One hundred (79%) participants completed the eight-week intervention with an identical

Table 2 Characteristics of studies on fish consumption and metabolic syndrome (MetS), organized by study design (intervention, prospective, cross-sectional)

Reference	Country/design	Aim	Population	Diet	Adjustments	Results adjusted OR (95% CI) incidence/prevalence of MetS
Ramel et al., 2009 [10]	Iceland RCT, part of SEAFOODplus YOUNG study 8w parallel intervention	Investigate whether cod consumption increases weight loss and CVD risk factors	n = 126, 20–40 y, overweight healthy, no gender distribution given	Energy-restricted diets (−30%), identical macronutrient composition, different amounts of cod (control group: no seafood, group 1: 150 g cod 3x/w, group 2: 150 g cod 5x/w)	In linear model with waist (baseline anthropometric measure, gender, diet group), and with blood variables (baseline anthropometric measure, weight loss, gender, diet group)	No association
Baik et al., 2010 [11]	Korea 3 y follow up Korean Genome Epidemiology Study	Investigate effect of fish and n-3 fatty acid intake on incidence of MetS	n = 3504, 40–69 y 52% men, free of MetS and CVD at baseline	FFQ Average fish intake was grouped (<1/week, 1-4/week, 5-6/week and daily)	Age, BMI, income, occupation, marital status, education, smoking, alcohol, physical activity, dietary intake (energy, fat, fibre, red meat, dairy products, sweetened car bonated beverage, multivitamin), health (diabetes, hypertension, menopausal status, postmenopausal hormone use)	Men: Average daily intake of fish (40–70 g) reduced the risk of having MetS, compared with eating fish less than once a week OR 0.43 (0.23-0.83) Women: No associations
Kouki et al., 2011[12]	Finland Cross-sectional, DR's EXTRAStudy	Studie associations between food items and nutrients versus the risk of having MetS	n = 1 334, 57–78 y 50% men Representative population sample	4-day food record Consumption of fish divided into tertiles (<18.5, 18.5–59.5, (>59.5 g/day)	a, Age, alcohol consumption, smoking b, Further for education, VO_2max	Men: the middle and highest tertile had almost half the risk of having MetS, compared to lowest tertile. a, t2: 0.51 (0.33–0.77) t3: 0.53 (0.35–0.81)b, t2: 0.52 (0.32–0.83) t3: 0.63 (0.40–1.00) Women: No association
Lai et al., 2013 [13]	Cross-sectional National Heart, Lung, and Blood Institute Family Heart Study	Assess association between dietary omega-3 fatty acids and MetS prevalence	n = 4941, mean age (SD) 52.1 (13.9) y 46% men	FFQ (fish consumption classified as 0, 1, 2, ≥3 servings/ week)	Age, gender, race, alcohol intake, smoking, exercise, TV watching, energy intake, multivitamin use, fruits/ vegetables intake, fibre intake, risk group	No association
Pasalic et al. 2011[14]	Croatia Cross-sectional	Investigate prevalence of MetS, and influence of lifestyle habits between continental and Mediterranean–Adriatic centres	n = 320, 70–90 y, 44% men	FFQ Consumption of fish grouped into never/rarely or monthly	Centres	No association
Ruidavets et al., 2007[15]	France Cross-sectional	Analyse relation between food groups and frequency of IRS	n = 912, 100% men 45–64 years randomly selected	3-day food record fish consumption divided into tertiles	Age, centre, physical activity, education, smoking habits, alcohol consumption, drugs (hypertension, dyslipidaemia), energy intake (without alcohol), dieting, and diet quality index	A negative association between fish intake and prevalence of MetS OR 0.57 (0.38-0.86), when comparing highest tertile to lowest

Table 2 Characteristics of studies on fish consumption and metabolic syndrome (MetS), organized by study design (intervention, prospective, cross-sectional) *(Continued)*

Zaribaf et al., 2014[16]	Iran Cross-sectional	Association between fish consumption and metabolic syndrome and its components	n = 420, 100% women, >30 y	FFQ fish consumption divided into tertiles	Age, energy intake, physical activity, socioeconomic status, medication use, marital, menopausal status, dietary intake (red meat, grains, fruits, vegetables, legume, nuts, dairy products, fibre, oils), BMI	Individuals in the highest tertile of fish intake were less likely to have MetS, compared to those in the lowest tertile OR 0.04 (0.004–0.61)

BMI: Body Mass Index; CI: confidence interval; CVD: cardiovascular disease; FFQ: Food Frequency Questionnaire; DBP: diastolic blood pressure; IRS: insulin resistance syndrome; MetS: metabolic syndrome; OR: odds ratio; RCT: randomized clinical trial; SBP: systolic blood pressure; WC: waist circumference.

macronutrient composition and various amounts of cod (control: no seafood; group 1: 150 g cod three times a week; group 2: 150 g cod five times a week). MetS was defined according to the definition from the International Diabetes Federation (IDF) [17] (Table 1), and compliance to seafood consumption was assessed with a validated food frequency questionnaire (FFQ). Different variables were included in linear models when analyzing anthropometric measures and blood variables, waist (baseline anthropometric measure, gender, diet group), and blood variables (baseline anthropometric measure, weight loss, gender, diet group). After eight-weeks of intervention, MetS prevalence dropped from 29% to 21% in the total study population, in addition to a reduction in the components of MetS: waist circumference (WC) (5.0 ± 3.2 cm, $P < 0.001$), systolic (3.4 ± 8.9 mmHg, $P = 0.001$) and diastolic blood pressure (BP) (2.4 ± 6.9 mmHg, $P < 0.001$), and triglycerides (TG) (1.26 ± 0.567 mmol/L, $P = 0.03$). The decrease in WC was greater (−3.4 cm, $P < 0.001$) among subjects consuming cod (150 g) 5x/week, compared to the control group. However, the BP was slightly higher in the groups consuming fish, compared to the control group, with systolic BP 5.3 mmHg higher ($P = 0.005$) for those consuming cod 5x/week and diastolic BP 3.2 mmHg higher ($P = 0.022$) for those consuming cod 3x/week. Blood lipids and glucose were not affected in the cod consumption groups [10].

Prospective studies

The follow-up study [11] included male and female Koreans (n = 3504) aged 40–69 years from the Korean Genome Epidemiology Study, a population-based prospective cohort study. Participants with MetS at baseline were excluded. MetS was defined according to the definition from the Adult Treatment Panel III (ATP III) [18], except for WC, where alternative criteria were used for the appropriate waist cut-off points [19] (Table 1). Associations between average frequency of fish consumption (sum of dark- or white-meat fish and canned tuna), and incidence of MetS were investigated. The average frequency of fish intake was grouped into <1/week, 1-4/week, 5-6/week, and daily, with the lowest intake category (<1/week) used as reference. Potential confounding factors were adjusted for (Table 2). The study reported a 17% incidence of MetS over the follow-up period, whereof 57% were men. The results showed that the adjusted risk of having MetS decreased to less than half (OR 0.43, 95% CI 0.23-0.83) among men who consumed fish daily, compared with those who consumed fish less than once a week. Furthermore, fish consumption was significantly associated with a lower TG level ($P < 0.01$) and an elevated high-density lipoprotein (HDL) cholesterol level ($P < 0.01$) among men. However, no significant association was found among women [11].

Cross-sectional studies

In a large Finnish population (n = 1334) associations between food and nutrients and the risk of having MetS were studied [12], where MetS was defined according to the ATP III definition [20] (Table 1). Baseline data from a population-based randomized controlled trial (RCT), the Dose Responses to Exercise Training (DR's EXTRA) study, was used. Dietary intake was assessed by a four-day food record, which included three weekdays and one weekend day, and utilized a picture booklet of portion sizes. MetS prevalence in the Finnish population was 28% among men and 25% among women. Individuals with MetS had a lower consumption of fish (g/d) compared to those without MetS, although the difference was only significant among men ($P = 0.001$). After adjusting for age, smoking status, and alcohol consumption, there was an inverse association between fish consumption (10 g/d) and MetS in men (OR 0.97, 95% CI 0.94–1.00). After further adjusting for cardiorespiratory fitness (VO_{2max}), the association was no longer significant. When dividing fish consumption into tertiles, men in the middle (18.5–59.5 g/day) and highest tertile (>59.5 g/day) had almost half the risk of having MetS, compared to those in the lowest tertile (<18.5 g/day) ($P = 0.002$), when adjusting for age, smoking status, and alcohol consumption. This association remained significant after additional adjustments for VO_2max and education (0.04). No significant associations was found in women [12].

In a US population, the associations between fish consumption and MetS were studied cross-sectionally in a large population (N = 4941) from the National Heart, Lung, and Blood Institute (NHLBI) Family Heart Study [13]. MetS was defined according to the ATP III definition [21] (Table 1), and frequency of fish intake was obtained from a FFQ and classified as 0, 1, 2, or 3 or more servings per week. Potential confounding factors were adjusted for (Table 2). In this population, with a MetS prevalence of 21.0%, no association was found between fish consumption and MetS prevalence. A higher consumption of fish was, however, related to a higher TG, compared to no fish consumption (155.8 mg/dL vs. (144.6 mg/dL) [13].

In a healthy elderly Croatian population (aged 70–90 years) from four centres (two continental and two coastal), MetS prevalence and characteristics were investigated [14]. MetS was defined according to the IDF definition [22] (Table 1). Dietary intake was assessed by food questionnaires related to eating habits. Consumption of fish was grouped monthly (or more frequent) and included pelagic fish (anchovy and/or mackerel and/or tuna) and freshwater fish (carp and/or catfish and/or trout). In this elderly population, with a 60-70% prevalence of MetS, there was no significant difference in MetS prevalence and fish consumption even after adjusting for centre-related variables. Nevertheless, a higher prevalence of men with

high HDL-cholesterol was observed among those frequently consuming pelagic fish, compared to those without frequent fish consumption (P = 0.03) [14]. MetS prevalence was significantly lower (P = 0.05) among participants from small centres (59%), who consumed more lard, freshwater fish, spirits, and wine, versus those from large centres (70%), although only wine consumption reached significance (P = 0.05). Still, there was no difference between continental and coastal centres or in prevalence of MetS among men and women [14].

In a French population, consisting only of men (aged 45–64 years) randomly selected from three regions in France, the relation between food groups and frequency of IRS were examined [15]. IRS was defined according to the ATP III definition [20] (Table 1), and dietary intake was assessed via a three-day food record. The consumption of fish (g/d) (sea fish, river fish, and seafood) was grouped into tertiles, due to the high percentage of non-fish eaters, and potential confounding factors were adjusted for (Table 2). In this population IRS prevalence was 24%, however, the prevalence reached 29% when fish consumption was below the median. A negative association between IRS and fish consumption was found, and proportions of IRS decreased along tertiles for fish consumption (adjusted OR 0.57, 95% CI 0.38-0.86) in the highest tertile of fish consumption [15].

Finally, the cross-sectional study from Iran [16] aimed to identify associations between fish consumption and MetS and its components in a population of women. MetS was defined according to the JIS definition [2] (Table 1). Female nurses (aged >30 years) were randomly selected from various hospitals in Iran (n = 420). Fish consumption was assessed using a FFQ and calculated by the summation of fish and tuna consumption, based on tertile cut-off points of energy-adjusted fish intake. The analysis adjusted for potential confounding factors (Table 2), and uncovered an 8% prevalence of MetS among this population of young women. The research revealed that high fish consumption was inversely associated with MetS, and some of its features (low HDL-cholesterol, hypertriglyceridemia, high BP). Women in the highest tertile of fish consumption were less likely to have MetS, compared with their counterparts in the lowest tertile (OR 0.35, 95% CI 0.14-0.88), and the association was strengthened when adjusting for socio-demographic and dietary variables, and BMI (OR 0.04, 95% CI 0.004-0.61) [16].

Discussion

In this systematic review, we explore how fish consumption affects MetS development and prevalence. A total of seven studies were found to be eligible for inclusion in the review, of which four studies revealed associations between fish consumption and MetS: one follow-up study [11] and three cross-sectional studies [12,15,16]. However, only one study found associations among women [16]. Despite data scarcity, the results suggest that fish consumption may have a preventive role in MetS development and possibly improve metabolic health, although this protective role might be gender-related.

Prevalence and incidence of metabolic syndrome

In five of the studies included in this review [10-13,15], there were small differences in MetS prevalence (21%-29%). The prevalence in the French study, reached 29% when fish consumption was below median consumption [15]. In the group from Iceland, MetS prevalence was 29% [10], which is surprisingly low for an overweight/obese population, although they were young and regarded as otherwise healthy [10]. The review did, however, include two studies that differed in MetS prevalence: an 8% prevalence of MetS was reported in the young population of women from Iran [16], while a 60-70% MetS prevalence was reported for the elderly population from Croatia [14]. Interestingly, the prevalence in the latter study was significantly lower (P = 0.05) among participants from small centres (59%), where they consumed more lard, freshwater fish, spirits, and wine in comparison with those from large centres (70%). However, a significant difference was only seen among participants in the wine consuming groups, with a lower prevalence of MetS in the group reporting daily wine consumption (P = 0.05). Still, there was no difference between continental and coastal centres or in prevalence among men and women [14]. Some studies, not included in this review, found an increased prevalence of MetS among men [12,23-25], some among women [26,27], and some studies found no gender differences [14,28,29].

The Korean follow-up study [11] included in this review reported a 17% incidence of MetS over the follow-up period, whereof 57% were men. An inverse association between daily fish consumption and MetS incidence was found among men, but not among women.

Metabolic syndrome, fish consumption and gender

Three of the five cross-sectional studies included in this review uncovered associations between fish consumption and MetS [12,15,16]. Nevertheless, two studies [12,15] found associations only among men, while one study found associations among women [16]. In the Finnish population both men and women with MetS had a lower fish consumption than those without MetS [12]. Furthermore, men in the highest tertile of fish consumption had almost half the risk of having MetS, compared to those in the lowest third (P = 0.002) [12]. In the French study [15], where the population consisted only of men, the risk of developing IRS was twice as high

for those whose fish consumption fell below the median value (33 g/day), versus those who consumed above the median value (OR 0.51, 95% CI 0.36-0.71) [15]. In the study from Iran [16], which only included women, high fish consumption was inversely associated with MetS, but here the fish consumption was based on tertile cut-off points of energy-adjusted fish consumption [16]. Only two cross-sectional studies failed to discern an association between fish consumption and MetS prevalence [13,14], although the Croatian study found a higher prevalence of men with high HDL-cholesterol among those frequently consuming pelagic fish compared to those without frequent fish consumption [14]. However, the study [14] did not differ between high and low consumers of fish, and it is therefore not possible to explore whether the results were associated with high or low fish consumption.

Differences in results found among men and women have been previously observed in studies investigating MetS and dietary patterns containing fish. A study from Spain (n = 808) [30] found an inverse association between Mediterranean diet (Med Diet) and risk of having MetS, although the association was significant only in men (P = 0.005), not in women (P = 0.056). This perhaps suggests that fish consumption may prevent or improve metabolic health and decrease MetS prevalence, and that differences in associations may be related to gender and lifestyle factors. A Korean study investigating associations between MetS and different dietary patterns in women found an inverse association between MetS and a healthy dietary pattern containing fish (OR 0.58, 95% CI 0.50-0.91) for highest versus lowest quartile. When stratifying by menopausal status, the inverse association was only significant among postmenopausal women (OR 0.60, 95% CI 0.40-0.86) for highest versus lowest quartile [31]. This may suggest gender differences, at least until menopause, and that premenopausal woman may have some natural protection against MetS, possibly from higher oestrogen levels and the ability of oestrogen to decrease inflammation and reduce the glucocorticoid response [32].

In women, parity and having a higher number of children have been associated with higher rates of MetS [33], and an increased prevalence with age has also been observed [31]. None of the included studies adjusted for parity or length of lactation in women, possibly resulting in different result among women. Lactation imposes a metabolic burden on the mother due to an increased energy requirement [34,35], and changes that occur during pregnancy (visceral fat accumulates, insulin resistance, increased lipid and TG levels) may reverse more quickly and more completely with lactation [36-38]. Moreover, prolonged lactation may be associated with a healthier metabolic profile and body composition, especially lipid levels and waist-to-hip ratios [38].

Metabolic syndrome and lean fish

In the intervention study from Iceland [10], the effect of lean fish (cod) was examined in an overweight/obese population. The intervention resulted in a drop in MetS prevalence among the total study population, although blood lipids and glucose were not affected by consumption of cod. This reduction in MetS prevalence may therefore be attributed to weight loss rather than the consumption of cod. However, the decrease in WC was greater among the cod consuming groups, compared to the control group [10].

A Spanish intervention study investigating the effect of white fish on CV risk factors in patients with MetS found that lean fish (seven servings of hake per week) reduced both WC and diastolic BP [39]. One possible explanation for the protective effects is that lean fish, such as cod, are considered a superior source of proteins. Proteins in fish have been associated with body weight reduction, through their positive effect on satiety, compared to other animal proteins [40]. The proteins in fish are easily digestible and rich in essential amino acids. Dietary proteins regulate lipid metabolism, depending on the quantity of proteins and composition of the diet, and have been seen to slow absorption and synthesis of lipids, and promote the lipid excretion [41]. Animal studies have suggested that fish protein may have multiple effects on plasma and liver lipids [42], and that consumption of fish protein might have beneficial effects on hyperglycaemia and hyperlipidaemia [43,44]. An improved insulin sensitivity has also been seen in insulin-resistant men and women consuming proteins from cod, compared to other animal proteins [45].

Metabolic syndrome, lifestyle and dietary pattern

Lifestyle habits, like dietary and behaviour lifestyle, as well as socioeconomic status (SES) appear to influence the prevalence and development of MetS across gender, age, and race/ethnicity [3]. Over the years, a number of individual foods and nutrients (e.g., fats, meat, fruits, vegetables, fish, dietary fibre) have been associated with MetS, although no single nutrient has been proposed entirely responsible. MetS has been associated with an unhealthy lifestyle, and positive associations with a diet high in processed foods such as refined grains, rice, potato chips, and pancakes have been observed [46]. When different healthy foods are consumed together, there may be an additive effect, and in one of the cross-sectional studies included in this review [14], an inverse association with MetS was found when fish was consumed with legumes, nuts and berries monthly or more frequently. However, this was seen only among men [14]. Such possible additive effects have also been observed when fish is consumed together with dairy products and grain [15], or when associations between MetS and dietary

patterns containing fish have been investigated in follow-up studies such as Healthy Diet [47] and Med Diet [48,49]. Still, not all follow-up studies point to associations between MetS and dietary patterns containing fish [50]. Of the cross-sectional studies investigating associations between MetS and dietary patterns containing fish, beneficial associations were seen in six studies [25,27,30,31,51,52], while ten cross-sectional studies failed to establish such association [23,24,26,28,29,46,53-56].

When examining dietary patterns, the pattern can be either a known dietary pattern used earlier in other studies or a dietary pattern revealed in the actual population. Dietary pattern analysis may capture the effects of dietary exposure, which often are lost in single nutrient or food analyses. However, the use of dietary patterns may be misleading and may hide positive effects of different foods when the dietary intake is summarized into categories or dietary patterns. Different food or food groups may also work against each other, such as when healthy food is placed in a group with unhealthy food, for example when fish and shellfish and the consumption of meat, processed meat, mayonnaise, and eggs are placed into one category [23]. Still, the effects of higher fish consumption may be associated with a healthier lifestyle. Thus, other factors included in a healthy lifestyle such as other healthy foods and a higher level of physical activity may be confounding factors. Of the studies included in this review, most contained some form of adjustment for diet and physical activity.

In the US population included in this review [13], a higher TG level was observed in those consuming fish versus those with no fish consumption. However, the study's method did not account for how the food is cooked, the positive health effects may diminish or vanish depending on how the meal is prepared, as has been demonstrated in fried fish in studies concerning CVD [57] and DM2 [58]. Therefore, any association may be linked to foods such as fish, to the dietary pattern, or to additive effects of different foods consumed. Today, lifestyle interventions remain the primary therapy for MetS [59], and it is therefore important to focus on lifestyle factors such as diet and different foods such as fish and their possible MetS-related health implications.

The use of different definitions of metabolic syndrome

Most of the studies included in this review are European, but inter-comparability is complicated by the various MetS criteria employed in the studies (Table 1). Moreover, different definitions may lead to higher or lower MetS prevalence, and higher prevalence of MetS has been seen in studies using the JIS definition [60]. Different populations may also have differences in the amount of abdominal fat, and it is therefore recommended to use a population- and country-specific definition for elevated WC as measures for abdominal obesity [2]. In the included Korean study [11], the European criteria for WC was considered too large. Alternative criteria based on national survey data in Korea was therefore used as the appropriate waist cut-off point for central obesity [11].

Conclusions

The results from this systematic review suggest that fish consumption may have a protective role in MetS prevention, and suggest that fish consumption may prevent or improve metabolic health. With the rapidly rising prevalence of MetS, further investigation is warranted to establish the ability of fish to improve or reverse MetS and its components, especially regarding any associations according to gender and lean fish.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

This work was carried out in collaboration between the authors. CT drafted the main part of the manuscript, and the manuscript was edited by MM and MCS. All authors read and approved the final manuscript and take full responsibility for the final content. The manuscript's preparation was performed without a specific grant from any funding agency in the public, commercial or not-for-profit sectors.

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