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Association between red meat consumption and metabolic syndrome in a Mediterranean population at high cardiovascular risk: Cross-sectional and 1-year follow-up assessment

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Abstract *Background and aims:* Little is known about the role that red meat and processed red meat (RM) consumption plays in the development of the metabolic syndrome (MetS).

The aim was to assess the relationship between RM consumption and the prevalence or incidence of the MetS and its components in a Mediterranean population at high risk of cardiovascular disease. *Methods and results:* Cross-sectional analyses were carried out at baseline and at 1-year follow-up and longitudinal analysis were conducted in a cohort of individuals at high risk of cardiovascular disease from the PREDIMED study. A 137-item validated semi-quantitative food frequency questionnaire, anthropometric measurements, blood pressure, fasting plasma glucose and lipid profile were evaluated both at baseline and after 1-year follow-up. The MetS was defined in accordance with the updated ATP III criteria.

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Subjects in the upper quartile of RM consumption were more likely to meet the criteria for the MetS at baseline (OR, 2.3; 95% CI, 1.4—3.9; *P*-trend = 0.001) and after 1-year follow-up (OR, 2.2; 95% CI, 1.3—3.7; *P*-trend = 0.034) compared with those in the quartile of reference, even after adjusting for potential confounders.

The longitudinal analyses showed that individuals in the fourth quartile of RM consumption had an increased risk of MetS (OR, 2.7; 95% CI, 1.1—6.8; *P*-trend = 0.009) or central obesity incidence (OR, 8.1; 95% CI, 1.4—46.0; *P*-trend = 0.077) at the end of the follow-up compared to the lowest quartile.

Conclusions: Higher RM consumption is associated with a significantly higher prevalence and incidence of MetS and central obesity in individuals at high risk of cardiovascular disease.
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Introduction

The Metabolic Syndrome (MetS), is a cluster of metabolic abnormalities which includes type 2 diabetes or impaired glucose tolerance, hypertension, dyslipidemia and central obesity, and which confers an increased risk of cardiovascular disease [1]. The MetS is considered an important 21st century public health problem because its prevalence has exponentially increased, affecting around 25% of the population in the developed world in parallel to global obesity and diabetes [2].

Several environmental factors and genetic determinants have been associated with the development and evolution of this syndrome [3]. A whole body of scientific evidence suggests that a healthy lifestyle and adherence to a prudent diet are associated with a lower prevalence of the MetS [4,5]. Conversely, a Western dietary pattern (rich in red meat and processed red meat, refined carbohydrates and low in dietary fibre) is directly related to a higher prevalence [4] or incidence [6] of this condition.

Several studies have associated red meat and processed red meat (RM) with an increased risk of type 2 diabetes [7,8], hypertension [9] or central obesity [10], all of which are the features of the MetS.

To date, three cross-sectional studies [11—13] and two prospective studies [6,14] have explored the relationship between RM and the risk of the MetS. Some studies showed a direct relationship between RM consumption and MetS [6,11—13]. However, the study by Damião et al. showed no association between several dietary factors (among them, red meat consumption), and risk of MetS after adjusting for the intake of saturated fat and other confounding variables [14].

To our knowledge, the possible association between RM consumption and MetS has never been prospectively explored in a population at high cardiovascular risk. Therefore, the aim of the present study was to examine the relationship between RM consumption and the prevalence and incidence of the MetS or its components in a large cohort of individuals at high cardiovascular risk.

Methods

Study population

This study has been conducted within the frame of the PREDIMED trial (http://www.predimed.org). The design of the PREDIMED trial (http://www.controlled-trials.com/ISRCTN35739639) has been reported in detail elsewhere [15]. The PREDIMED study is a long-term nutritional intervention study aimed at evaluating whether the Mediterranean diet supplemented with extra-virgin olive oil or tree nuts prevents cardiovascular diseases (cardiovascular death, myocardial infarction and/or stroke) compared with a control (low fat) diet. The individuals studied are men aged between 55 and 80 and women aged between 60 and 80 years without previously documented cardiovascular disease but at high cardiovascular risk. Inclusion criteria were type 2 diabetes mellitus, or the presence of two or more of the following cardiovascular risk factors: hypertension, hypertrygliceridemia (serum triglyceride $\geq$150 mg/dL or requiring treatment), low plasma HDL-cholesterol levels ($\leq$ 40 mg/dL in men and $\leq$50 mg/dL in women), overweight or obesity (BMI between 28 and 40 kg/m^2), smoking, or a family history of premature coronary heart disease. All patients included in the present study were from the Reus-Tarragona area and had undergone at least 1-year follow-up in the PREDIMED trial at the moment of the analysis. Data were analysed as an observational prospective cohort because RM consumption was not a part of the intervention.

Of the 870 enrolled participants randomized between October 2003 and July 2008, 739 were followed-up for at least 1-year. Twenty-two subjects were excluded from the present analysis because they did not have baseline or 1-year values for food, energy intake, the MetS components or other covariates. The effective sample size for statistical analyses was 717 participants. All participants provided informed consent and the protocol was approved by the institutional review boards.

Dietary assessment

A 137-item previously validated food frequency questionnaire for the PREDIMED study [16] was used to appraise dietary habits at baseline and after 1-year follow-up.

In the validation study, the intra-class correlation coefficient for all meats/meat products considered together was 0.75 and total energy intake was 0.75 and 0.53 respectively. Spanish food composition tables were used to derive nutrient composition [17]. The RM variable included the consumption of pork, veal, lamb, several types of sausages and processed red meat derivates.

Metabolic syndrome

The updated criteria from the National Cholesterol Education Program's Adult Treatment Panel III were used to define MetS [1]. Subjects were considered to have MetS if they have presented ≥3 of the following: (1) waist circumference >102 cm in men and >88 cm in women; (2) serum triglyceride ≥150 mg/dL; (3) HDL-cholesterol <40 mg/dL in men and <50 mg/dL in women; (4) blood pressure ≥130/85 mmHg; and (5) fasting plasma glucose level ≥100 mg/dL. Participants who were being treated with antidiabetic, antihypertensive or triglyceride-lowering medications were considered as diabetic, hypertensive or hypertriglyceridemic, respectively.

Assessment of other covariates

Cardiovascular risk factors, medical conditions, medication use and socio-demographic and lifestyle conditions were assessed at baseline and 1-year follow-up, by structured interviews and questionnaires. Smoking status was categorized into never, current or past smoking according to self-reports. The validated Spanish version of the Minnesota Questionnaire [18] was used to estimate total energy expenditure in leisure-time physical activity.

Height and weight were measured with light clothing and no shoes by trained staff. Body mass index was calculated as the weight (kg) divided by the square of the height (m^2). Waist circumference midway between the lowest rib and the iliac crest was measured by using an anthropometric tape. Blood pressure was measured in duplicate with a 5-min interval between each measurement, and the mean of these values was recorded. Blood pressure was measured using a validated semi-automatic oscillometer (Omron HEM-705CP, Hoofddorp, Netherlands).

Centralized laboratory biochemical analyses were performed on blood obtained after at least 12 h of fasting conditions. Plasma glucose and serum cholesterol and triglyceride levels were measured using standard enzymatic automated methods. HDL-cholesterol was measured as cholesterol by enzymatic procedure after precipitation with phosphotungstic acid and magnesium chloride.

Statistical analyses

Participants were categorized into quartiles of RM consumption at baseline and 1-year follow-up. Food and nutrient intake were adjusted for total energy intake using the residual method [19].

To test differences in the general characteristics across quartiles of RM consumption, one-way ANOVA and chi-square tests were used.

Multiple logistic regression models were fitted in order to asses the association between the prevalence of MetS across quartiles of RM consumption at baseline and at 1-year follow-up. Three models were constructed: unadjusted model (Model I), adjusted model for sex and age (Model II), adjusted model including age, sex and other potential confounders, such as total energy intake, body mass index, smoking, and leisure physical activity, and dietary potential confounders such as baseline alcohol,

Table 1 Baseline characteristics of the participants across the quartile of red meat and processed red meat (RM) consumption.

	Q1 *n* = 180	Q2 *n* = 173	Q3 *n* = 187	Q4 *n* = 177	*P*
RM intake, g — mean ± SD	35.9 ± 14.5	66.0 ± 7.2	91.6 ± 8.4	150.6 ± 35.9	<0.001
Age, years — mean ± SD	68.0 ± 6.0	67.9 ± 5.5	67.6 ± 6.0	66.4 ± 5.9	0.045
Men, % (*n*)	28.9 (52)	37.6 (65)	48.1 (90)	58.8 (104)	<0.001
BMI, kg/m^2 — mean ± SD	29.3 ± 3.2	29.7 ± 3.3	29.8 ± 3.3	29.6 ± 3.3	0.595
Waist circumference, cm — mean ± SD	99.3 ± 8.5	101.0 ± 8.7	101.7 ± 8.7	101.7 ± 8.8	0.033
Leisure physical activity, kcal— mean ± SD	226 ± 184	281 ± 272	254 ± 222	313 ± 317	0.009
Smokers, % (*n*)					
Never	76.1 (137)	67.1 (116)	57.2 (107)	51.4 (91)	<0.001
Current	5.6 (10)	9.8 (17)	10.7(20)	18.6 (33)	
Past	18.3 (33)	23.1 (40)	32.1 (60)	29.9 (53)	
Metabolic syndrome, % (*n*)	56.1 (101)	61.8 (107)	65.2 (122)	66.1 (117)	0.193
Central obesity, % (*n*)	77.2 (139)	79.8 (138)	77.0 (144)	70.1 (124)	0.170
Hypertrigliceridemia, % (*n*)	30.0 (54)	31.2 (54)	25.7 (48)	37.3 (66)	0.119
Low HDL-c level, % (*n*)	16.7 (30)	22.0 (38)	24.1 (45)	20.9 (37)	0.362
Hypertension, % (*n*)	96.7 (174)	93.6 (162)	95.2 (178)	98.3 (174)	0.143
Fasting plasma glucose level ≥100, % (*n*)	54.4 (98)	58.4 (101)	70.1 (131)	66.7 (118)	0.007
Current medication use, % (*n*)					
Antihypertensive treatment	77.8 (140)	74.0 (128)	71.1 (133)	80.2 (142)	0.187
Lipid-lowering drugs	49.4 (89)	44.5 (77)	47.1 (88)	36.7 (65)	0.085
Oral hypoglycaemic agents	30.6 (55)	32.4 (56)	37.4 (70)	33.3 (59)	0.552
Insulin therapy	3.9 (7)	8.1 (14)	8.6 (16)	4.0 (7)	0.105

Abbreviations: Q: quartile; SD: Standard deviation; HDL-c: high-density lipoproteins cholesterol.

dietary fibre, magnesium and potassium consumption (Model III). In all the models, the first quartile of the RM consumption was considered as the reference. All multiple logistic regression models were additionally adjusted for the intervention group at 1-year follow-up.

Interaction tests for sex (product-terms, sex * RM) showed that there were no statistically significant differences between men and women in terms of the association between RM and the occurrence of MetS.

A longitudinal analysis was conducted (exposure: baseline quartiles of RM consumption; outcome: incidence of MetS or each of its components after 1-year follow-up) in order to longitudinally evaluate the relationship between RM consumption (divided into quartiles, taking the lowest quartile as reference) and 1-year incidence of MetS or its components. This longitudinal study included only participants without the MetS (or without each particular feature of the MetS) at baseline. We adjusted longitudinal analyses for sex, age, total energy intake, body mass index, smoking, leisure physical activity, baseline alcohol, dietary fibre, magnesium, and potassium intake, and the intervention group.

We ensured that specific assumptions of all statistical tests were fulfilled. The level of significance for all statistical tests was $P < 0.05$ for bilateral contrasts. All analyses were performed with SPSS version 17.0 (SPSS Inc., Chicago, IL).

Results

General characteristics of participants across quartiles of RM consumption are presented in Table 1. Subjects in the higher quartiles of RM were mainly men, smokers, had a higher waist circumference and a significantly higher leisure-time physical activity. Impaired fasting glucose was significantly more prevalent among individuals in the upper quartile compared to those in the lowest quartile. Furthermore, total energy intake, alcohol consumption, cholesterol, dietary fibre, iron, sodium, magnesium and potassium intake were higher among the subjects in the top quartile (Table 2).

Cross-sectional analysis at baseline and 1-year follow-up

At baseline, participants in the upper quartile of RM consumption were significantly more likely to meet the criteria for the MetS (Table 3), even after controlling for potential confounders (Model III) compared with those in the lowest quartile (OR, 2.3; 95% CI, 1.4—3.9; P for linear trend = 0.001). At 1-year follow-up, subjects in the top quartile also had twice the risk of having the MetS (OR, 2.2; 95% CI, 1.3—3.7; P for linear trend = 0.034) compared to those individuals in the reference quartile. The linear trend

Table 2 Baseline dietary characteristics of participants across the quartile of red meat and processed red meat consumption.

	Q1 $n = 180$	Q2 $n = 173$	Q3 $n = 187$	Q4 $n = 177$	P
Red meat consumption, g/d — mean (range)	20.8 (18.9—22.7)	40.2 (38.2—42.2)	57.6 (55.1—60.0)	103.9 (98.0—107.7)	<0.001
Processed red meat consumption (range)	15.1 (13.4—16.6)	25.8 (24.0—27.6)	34.0 (31.8—36.3)	47.8 (44.1—51.5)	<0.001
Total energy intake, kcal/d — mean ± SD	2032 ± 508	2181 ± 474	2311 ± 527	2694 ± 628	<0.001
Protein					
% of total energy intake — mean ± SD	16.2 ± 2.7	16.8 ± 2.5	17.0 ± 2.6	16.9 ± 2.4	0.019
g/day — mean ± SD	81.2 ± 18.6	90.3 ± 16.8	96.9 ± 20.4	111.8 ± 21.3	<0.001
Carbohydrates					
% of total energy intake — mean ± SD	42.1 ± 6.4	40.1 ± 5.6	39.5 ± 6.0	37.8 ± 6.3	<0.001
g/day — mean ± SD	215 ± 69.6	221 ± 63.9	228 ± 69.1	256 ± 78.3	<0.001
Fat					
% of total energy intake — mean ± SD	39.9 ± 6.2	41.1 ± 5.7	40.9 ± 5.9	41.9 ± 6.0	0.018
g/day — mean ± SD	90.1 ± 25.7	99.2 ± 23.9	104.5 ± 26.4	125.4 ± 34.1	<0.001
Saturated fatty acid, g/d — mean ± SD	21.9 ± 6.8	25.4 ± 6.7	25.6 ± 6.7	35.2 ± 9.9	<0.001
Polyunsaturated, g/d — mean ± SD	14.8 ± 5.8	15.8 ± 5.8	16.3 ± 6.0	19.1 ± 6.7	<0.001
Monounsaturated, g/d — mean ± SD	46.1 ± 15.0	50.0 ± 13.2	52.0 ± 14.3	61.5 ± 18.7	<0.001
Alcohol, g/d — mean ± SD	5.3 ± 8.9	6.4 ± 10.0	9.3 ± 15.9	13.3 ± 16.4	<0.001
Vegetables, g/d — mean ± SD	296 ± 146	303 ± 124	306 ± 135	329 ± 129	0.104
Fruits, g/d — mean ± SD	319 ± 190	294 ± 160	308 ± 166	329 ± 178	0.278
Cholesterol, mg/d — mean ± SD	307 ± 95	358 ± 85	396 ± 109	469 ± 113	<0.001
Dietary fibre, g/d — mean ± SD	23.1 ± 8.4	22.6 ± 6.7	23.2 ± 8.3	25.2 ± 7.6	0.011
Iron intake, g/d — mean ± SD	14.5 ± 4.3	15.5 ± 3.8	16.4 ± 3.9	19.0 ± 4.4	<0.001
Sodium intake, g/d — mean ± SD	2140 ± 761	2351 ± 698	2656 ± 871	3144 ± 1080	<0.001
Magnesium intake, mg/d — mean ± SD	246 ± 102	354 ± 83	368 ± 102	406 ± 98	<0.001
Potassium intake, mg/d — mean ± SD	3929 ± 1125	4107 ± 968	4241 ± 1059	4705 ± 1036	<0.001

Abbreviations: Q: quartile; SD: Standard deviation.

Table 3 Risk of having MetS at baseline and 1-year of follow-up (*odds ratios* and their 95% confidence interval) across quartiles of red meat and processed red meat (RM) consumption.

	Quartiles of RM consumption at baseline					Quartiles of RM consumption at 1-year follow-up				
	Q1 $n = 180$	Q2 $n = 173$	Q3 $n = 187$	Q4 $n = 177$	*P* for trend	Q1 $n = 174$	Q2 $n = 188$	Q3 $n = 174$	Q4 $n = 181$	*P* for trend
RM&PM intake, g − mean ± SD	35.9 ± 14.5	66.0 ± 7.2	91.6 ± 8.4	150.6 ± 35.9	<0.001	29.1 ± 11.7	55.5 ± 6.1	78.2 ± 8.3	126.6 ± 29.3	<0.001
MetS prevalence, *n* (%)	101 (56.1)	107 (61.8)	122 (65.2)	117 (66.1)	0.043	101 (58.0)	121 (64.4)	116 (66.7)	120 (66.3)	0.097
Model I[a]	1	1.3 (0.8–1.9)	1.5 (1.0–2.2)	1.5 (1.0–2.3)	0.041	1	1.3 (0.8–2.0)	1.4 (0.9–2.2)	1.4 (0.9–2.2)	0.110
Model II[a]	1	1.4 (0.9–2.2)	1.8 (1.2–2.8)	2.1 (1.3–3.2)	0.001	1	1.4 (0.9–2.1)	1.7 (1.1–2.7)	1.4 (1.1–2.7)	0.011
Model III[a]	1	1.4 (0.9–2.2)	1.8 (1.1–2.9)	2.3 (1.4–3.9)	0.001	1	1.4 (0.9–2.3)	2.2 (1.3–3.6)	2.2 (1.3–3.7)	0.034

Abbreviations: Q: quartile; SD: Standard deviation; MetS: Metabolic syndrome.

[a] Multiple logistical regression (at 1-year follow-up; this was also adjusted for the intervention group). Model I: unadjusted model; Model II: adjusted for age and sex; Model III: adjusted for age, sex, smoking, body mass index, physical activity, total energy intake, dietary baseline variables (alcohol, dietary fibre, magnesium and potassium).

test remained significant after additionally adjusting for saturated fat and protein intake.

When red meat and processed red meat was evaluated separately, only processed red meat consumption at baseline was significant associated with a higher risk of having the MetS (OR, 2.3; 95% CI, 1.4—3.9; *P* for linear trend = 0.001). At 1-year follow-up this association also showed the same tendency (OR, 1.6; 95% CI, 1.0—2.7) but the linear trend test was only borderline significant ($p = 0.054$) (Supplementary Appendix 1).

Although the same tendency existed in the point estimates when the particular components of the MetS at baseline and at 1-year follow-up were assessed as outcome, no statistically significant differences were observed for participants in the top versus the lowest quartile of RM consumption and the prevalence of specific components of the MetS (data not shown).

Longitudinal analysis

Table 4 shows the association between baseline quartiles of RM consumption and the incidence of MetS during follow-up (longitudinal analysis). Participants initially free of the MetS who were in the top quartile of RM consumption at baseline had a 2.7 times greater risk of developing the MetS during follow-up (OR, 2.7; 95% CI, 1.1—6.8; *P* for linear trend = 0.009), even after adjusting for saturated fat and protein intake (OR, 3.7; 95% CI, 1.3—10.7; *P* for linear trend = 0.063).

Regarding the incidence of MetS, higher red meat or processed red meat consumption were analysed separately and were both associated with a higher risk of developing MetS (OR, 2.2; 95% CI, 1.0—5.1; *P* for linear trend = 0.030 for red meat, and OR, 2.5; 95% CI, 1.0—6.2; *P* for linear trend = 0.052 for processed red meat) (Supplementary Appendix 2).

In relation to the MetS components, individuals in the top quartile of baseline consumption of RM had 8.1 times greater risk of central obesity incidence (OR, 8.1; 95% CI, 1.4—46.0; *P* for linear trend = 0.077). Since 93% of the participants had hypertension at baseline, this component could not be analysed.

Discussion

The results of the present study show a direct association between red meat and processed meat consumption and the risk of the MetS. Furthermore, to our knowledge, this study is the first that prospectively demonstrates a higher incidence of MetS in those subjects consuming higher amounts of RM. These associations remained significant even after adjusting for potential dietary and non-dietary confounders. This is important, because the MetS has been considered an independent risk factor for diabetes [20] cardiovascular disease [21] and all-cause mortality [22].

The present findings are in agreement with other studies showing a relationship between red meat or processed red meat products and the prevalence of MetS. For example, in a cross-sectional analysis of the PREDIMED cohort, we have described in a previous study (in men only) how those who consumed less than one red meat serving per day had

Table 4 Risk of incidence of MetS and its components (odds ratios and their 95% confidence interval) across the quartiles of red meat and processed red meat (RM) consumption.

	Evolutionally longitudinal analysis[a]				
	Q1	Q2	Q3	Q4	*P* for trend
Metabolic syndrome	*n* = 79	*n* = 66	*n* = 65	*n* = 60	
Incidence, *n* (%)	16 (20.3)	15 (22.7)	24 (36.9)	20 (33.3)	0.025
	1	1.1 (0.5–2.7)	2.7 (1.3–7.2)	2.7 (1.1–6.8)	0.009
Central obesity	*n* = 41	*n* = 35	*n* = 43	*n* = 53	
Incidence, *n* (%)	6 (14.6)	9 (25.7)	6 (14.0)	15 (28.3)	0.230
	1	8.4 (1.6–5.2)	1.9 (0.4–9.8)	8.1 (1.4–46.0)	0.077
Hypertrigliceridemia	*n* = 126	*n* = 119	*n* = 139	*n* = 111	
Incidence, *n* (%)	15 (11.9)	16 (13.4)	18 (12.9)	18 (16.2)	0.390
	1	1.1 (0.5–2.4)	1.0 (0.5–2.1)	1.2 (0.5–2.9)	0.715
Low HDL-c level	*n* = 150	*n* = 135	*n* = 142	*n* = 140	
Incidence, *n* (%)	20 (13.3)	21 (15.6)	19 (13.4)	17 (12.1)	0.669
		1.3 (0.7–2.6)	1.1 (0.5–2.3)	1.1 (0.5–2.4)	0.928
Blood Pressure	*n* = 6	*n* = 11	*n* = 9	*n* = 3	
Incidence, *n* (%)	3 (50.0)	6 (54.5)	6 (66.7)	3 (100)	0.160
		–	–	–	–
IGT	*n* = 82	*n* = 72	*n* = 56	*n* = 59	
Incidence, *n* (%)	9 (11)	7 (9.7)	11 (19.6)	8 (13.6)	0.365
		0.9 (0.3–2.8)	1.6 (0.6–4.5)	1.2 (0.4–4.0)	0.547

Abbreviations: Q: quartile; IGT: impaired glucose tolerance.

[a] Multiple logistical regression (exposure: baseline quartile of RM consumption; outcome MetS and its components 1-year incidence) age, sex, smoking, body mass index, physical activity, total energy intake, dietary baseline variables (alcohol, dietary fibre, magnesium and potassium) and intervention group.

a lower risk of having MetS than those who consumed more than one serving per day. Unfortunately, that study was not able to demonstrate a linear trend between these two variables, because the consumption of red meat was assessed using a dichotomized variable [13]. Inline with our results, a recent cross-sectional analysis from a cohort of Tehrani women showed that those in the upper quintile of red meat consumption had a more than 2-fold greater odds of prevalent MetS than those in the lowest quintile [12].

To our knowledge, the association between red meat and MetS has been prospectively analysed in middle-aged adults enrolled in the Atherosclerosis Risk in Communities study [6] and in a cohort of low cardiovascular risk Japanese–Brazilian subjects followed for 7 years [14]. In both these studies, those individuals with the highest intake of red meat consumption had an increased risk of developing MetS, [6,14] an association that disappeared after adjustment for saturated fatty acids in the Brazilian study [14]. This may be due to an overadjustment because saturated fat may be more of a mediating rather than a confounding variable. It should be noted that in our study, the relationship also persisted after adjusting for the intake of saturated fatty acids and other dietary variables.

The association between RM and MetS in the present study is probably the result of the effect on multiple components. Although the only component of MetS that showed a significant association with the intake of RM was the incidence of central obesity, there was a tendency suggesting a potentially detrimental role of RM on other components of the syndrome, such as hypertrigliceridemia or low HDL-cholesterol.

The association observed in our study between RM consumption and central obesity is consistent with other prospective studies [10,23,24]. Other studies have shown an association between RM consumption and the risk of other components of the MetS such as hypertension [9] or diabetes [7]. In our study we have not been able to test the relationship between the intake of RM and blood pressure because more than 95% of our population had already elevated blood pressure at baseline. Regarding the glucose component of MetS, our study does not support the results of a recent meta-analysis of 12 cohorts which demonstrated a higher risk of type 2 diabetes in those subjects consuming higher amounts of total RM products [7]. The lack of significant association observed between the intake of meat and the individual components of metabolic syndrome could be due to the relatively short follow-up period. Also, the relatively wide confidence intervals for the results regarding the individual components of metabolic syndrome suggest only modest statistical power for detecting a significant effect on the incidence of metabolic syndrome features.

The mechanisms that might explain the adverse relationship between red meat consumption and the risk of MetS or its components are not well understood. Some authors suggest that this association might be because RM is important sources of saturated fatty acids and iron [14,6]. In fact, in our study, a linear increase in the intake of these nutrients was shown to be related to the increase in the consumption of red meat and processed meat products.

The intake of a high amount of saturated fat present in red meat and all the processed foods derived from RM could

increase the risk of developing MetS through weight gain [23,24]. In fact, there is some evidence that saturated fats are less thermogenic [25] and induce more weight gain in animals [26] compared with other vegetable sources of unsaturated fat. This was supported by the results of our study which showed a direct association between a higher RM consumption and the incidence of central obesity.

Iron, present in RM products, could also exert a detrimental role on inflammation and thus induce the development of MetS. Heme iron has been shown to be a cause of oxidative stress due to the increased formation of free radicals. This could affect several tissues, particularly the pancreatic beta cells, muscle and adipocytes, and thus induce insulin-resistance, beta cell dysfunction [27], and the release of iron from the ferritin stores.

Because of their high content in nitrates, nitrites, sodium and heterocyclic amines and aromatic polycyclic hydrocarbures formed during cooking or processing methods [28], a high intake of processed meat products such as bacon, sausages or hamburgers, could also contribute to the increase in blood pressure [29] and insulin-resistance [30], thus increasing the risk of hypertension and type 2 diabetes.

The present study has some limitations. The participants were older and at high cardiovascular risk, so our results cannot be generalized to other populations. Furthermore, it is likely that there are other confounder variables not controlled for in our analysis, such as the amount of nitrates, nitrites and heterocyclic amines consumed, which seem to play an important role in the onset and evolution of MetS and its components [31]. Another important limitation of our study is that it was conducted in a cohort under a nutritional intervention which might have a differential effect on the incidence of MetS or its components. However, we have kept this limitation in mind and have additionally adjusted all the analyses at 1-year follow-up according to the intervention group in order to minimize this effect. Another possible limitation is that our study could contain a reverse causation bias, that is, participants with known cardiovascular risk factors and participants who are more aware of their conditions might be more likely to change their diet or the reporting of their usual diets. Conversely, participants who do not change their diet (e.g. who still have a high meat intake) may be an indicator for poor treatment adherence, which in turn may also affect prudent use of medication.

In conclusion, the results of the present study suggest that higher RM consumption is associated with a greater risk of MetS. This is relevant because this condition has been considered an independent risk factor for cardiovascular disease [21]. Intervention studies are warranted in the future to obtain more evidence regarding the possible effect of consuming large amounts of RM on MetS and its components.

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Conflict of interest

None of the funding sources played a role in the design, collection, analysis or interpretation of the data or in the decision to submit the manuscript for publication.

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Appendix Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.numecd.2010.06.011.

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