Dairy food consumption is associated with a lower risk of the metabolic syndrome and its components: a systematic review and meta-analysis

Mijin Lee[1], Hanna Lee[2] and Jihye Kim[1]*

[1]*Department of Medical Nutrition, Graduate School of East-West Medical Science, Kyung Hee University, Yongin 17104, Republic of Korea*
[2]*Korea Federation of Women's Science and Technology Associations, Seoul 135-703, Republic of Korea*

Abstract

A systematic review and a meta-analysis of observational studies were performed to assess the dose–response relationship between specific types of dairy foods and the risk of the metabolic syndrome (MetS) and its components. Studies of dairy foods and the risk of the MetS and its components published up to June 2016 were searched using PubMed, EMBASE and a reference search. Random-effects models were used to estimate the pooled relative risks (RR) with 95 % CI. Finally, ten cross-sectional studies, two nested case–control studies and twenty-nine cohort studies were included for the analysis. In a dose–response analysis of cohort studies and cross-sectional studies, the pooled RR of the MetS for a one-serving/d increment of total dairy food (nine studies) and milk (six studies) consumption (200 g/d) were 0·91 (95 % CI 0·85, 0·96) and 0·87 (95 % CI 0·79, 0·95), respectively. The pooled RR of the MetS for yogurt (three studies) consumption (100 g/d) was 0·82 (95 % CI 0·73, 0·91). Total dairy food consumption was associated with lower risk of MetS components, such as hyperglycaemia, elevated blood pressure, hypertriacylglycerolaemia and low HDL- cholesterol. A one-serving/d increment of milk was related to a 12 % lower risk of abdominal obesity, and a one-serving/d increment of yogurt was associated with a 16 % lower risk of hyperglycaemia. These associations were not significantly different by study design, study location or adjustment factors. This meta-analysis showed that specific types of dairy food consumption such as milk and yogurt as well as total dairy food consumption were inversely related to risk of the MetS and its components.

Key words: Meta-analyses: Systematic reviews: Dairy food consumption: Metabolic syndrome

The metabolic syndrome (MetS) is a metabolic disorder involving abdominal obesity, dyslipidaemia, elevated blood pressure and insulin resistance, all of which increase the risk of CVD and type 2 diabetes[1]. The prevalence of the MetS is rapidly increasing worldwide[2,3]. It is estimated that 20–25 % of the world's adult population has the MetS[4].

Diet plays an important role in the development of the MetS[5]. Epidemiological studies have evaluated the relationship between dairy food consumption and risk of the MetS. Some studies reported an inverse association[1,6–12], but others showed no association[13–16]. The different results on the associations might be because of the effects of various types of dairy foods on the risk of the MetS. A recent study suggested that individual dairy foods might have different effects on the risk of the MetS. A higher consumption of regular-fat dairy products was associated with a reduced risk of the MetS, whereas low-fat dairy products were not associated with the MetS in middle-aged and older US women[10]. Inconsistently, a higher consumption of whole-fat yogurt and low-fat milk was associated with a reduced risk of the MetS, whereas whole-fat milk was not associated with the MetS, and a higher consumption of cheese was related to a higher risk of the MetS in a Mediterranean population[14].

Two meta-analyses have shown a significant relationship between dairy food consumption and the MetS[17,18]. However, these studies only assessed the relationship between total dairy food consumption and risk of the MetS. None of the studies have investigated the effects of specific types of dairy foods on the MetS and individual components.

Therefore, we performed a systematic review and a meta-analysis of observational studies on the relationship between specific types of dairy foods, such as milk and yogurt as well as total dairy foods, and the MetS and individual components (abdominal obesity, low HDL-cholesterol, hypertriacylglycerolaemia, hyperglycaemia and high blood pressure) in the general population.

Methods

Literature search strategy

A systematic literature search was conducted using PubMed and EMBASE from January 1900 to June 2016. The following search

terms were used: ('dairy' OR 'milk' OR 'yogurt') AND ('metabolic syndrome' OR 'metabolic syndrome X' OR 'diabetes' OR 'diabetes mellitus' OR 'hyperglycemia' OR 'high blood pressure' OR 'high density lipoprotein' OR 'dyslipidemia' OR 'triglyceride' OR 'obesity').

Study selection

For inclusion criteria in this meta-analysis, the studies had to be observational, have dairy food consumption as a dietary factor, have the MetS and/or its components (abdominal obesity, low HDL-cholesterol, hypertriacylglycerolaemia, hyperglycaemia, and high blood pressure) as outcomes and report relative risks (RR) or OR and CI (or data to calculate them) in healthy adults. The following studies were excluded: animal studies, randomised controlled trials, studies not published in English, studies that focused on patients who had specific diseases, studies not related to dietary factors (dairy foods) or outcomes (the MetS or its components), studies in which no full text was available, reviews and meta-analyses. In addition, the references from the retrieved articles and those from previous review studies were reviewed to identify additional relevant studies (Fig. 1).

Data extraction and quality assessment

Two investigators (M. L. and J. K.) conducted study selection and data extraction, and further discussion was performed to resolve any disagreement by reviewing the original article. The following data were extracted from each study: first author's last name, publication year, study location, study design, follow-up period, number of cases and subjects, age and sex of the subjects, type of outcome (MetS or individual components), type of dairy foods (total dairy foods, milk or yogurt), dietary assessment method, MetS criteria, OR or RR with the 95 % CI for the relationship between dairy foods 'consumption and the MetS across dairy product intake levels and adjustment for confounding factors. We used the most-adjusted model among multivariable adjustment models.

In this study, total dairy foods included milk, yogurt, cheese and dairy desserts such as custard and ice cream. Definitions of whole-fat dairy foods or low-fat dairy foods were differed across studies. Most studies described what type of dairy foods were included in the whole-fat or low-fat dairy foods without information on fat content. Whole-fat or regular-fat dairy foods included whole milk, whole-fat yogurt, regular cheese and medium-fat dairy dessert; whereas, low-fat or reduced-fat dairy foods included skimmed or low-fat milk, skimmed or low-fat yogurt, cottage/ricotta cheese or low-fat cheese and reduced-fat dairy dessert[1,6–16,19–23]. A few studies defined whole-fat or low-fat dairy foods by fat content. Whole-fat dairy foods were defined as milk and milk products with a total fat content of ≥2 g/100 g[24] or >3·5 g/100 g[25,26] or cheese products with a total fat content of ≥20 g/100 g[24–26], whereas low-fat dairy foods were defined as milk and milk products with a total fat content of <2/100 g or cheese with a total fat content of <20/100 g[24–26]. Whole-fat dairy foods were defined as whole-fat milk (4 % fat), whole-fat cheese (30–35 % fat) and cream (19–24 % fat)[27], whereas low-fat dairy foods were defined as

skimmed milk (0·3 % fat), semi-skimmed milk (1·7 % fat) and low-fat cheese (12–16 % fat)[27].

Two investigators (M. L. and J. K.) independently evaluated the quality of cohort studies using the Newcastle–Ottawa quality assessment scale[28] for the following criteria: representativeness of the exposed cohort; dietary assessment methods of dairy food consumption; assessment of outcome; duration of follow up; adequacy of the follow up of cohorts; and adjustment for important confounders (age, BMI, smoking, alcohol and physical activity). The evaluation scores ranged from 0 to 9. Total scores ≥7 (out of 9) indicated good quality. The quality of cross-sectional studies was evaluated using the strengthening the reporting of observational studies in epidemiology statement[29]. The evaluation score ranged from 0 to 22. Total scores ≥16 (out of 22) indicated good quality. Any discrepancies in quality assessment between two reviewers were resolved by discussion until a consensus was reached. To avoid selection bias, no study was rejected because of these quality criteria.

Statistical analysis

The pooled estimates (RR or OR) of the MetS and 95 % CI for the highest *v*. the lowest category of dairy food consumption level or the linear or non-linear dose–response analysis were obtained using random effects, which accounted for the heterogeneity among studies[30]. When a study provided the estimates for total dairy foods, low-fat dairy foods and whole-fat dairy foods, the effect estimates of total dairy food consumption were included in the main analysis. When a study reported the separate estimates for each dairy food according to fat content (skimmed/low-fat milk and whole/full-fat milk)[31–35] or sex (men and women)[36,37], the effect estimates from each dairy foods were combined using a fixed-effect model in the main analysis.

The dose–response relationship between dietary factor (total dairy foods, milk and yogurt) and outcome (MetS and its components) was examined using generalised least-square trend estimation analysis to estimate the study-specific slope lines first and then derive an overall slope, which requires the distribution of cases and person-years or subjects[38,39]. When these numbers were not available, a variance-weighted least squares meta-regression analysis was used to estimate the dose–response slopes[38,39]. For these two analyses, the median or the mean value for each category of intake levels was used. For studies not providing the median or mean consumption of each category, the midpoint of the upper and the lower boundary in each category was used as the average intake. Dairy food consumption reported as servings or portions per day, week or month was converted to g/d. One-serving/d was defined as 200 g for total dairy foods or milk, and 100 g for yogurt.

In addition, subgroup and meta-regression analyses were performed according to study design (cohort/cross-sectional), study location (Americas, Asia, Europe, Oceania) and adjustment factors (BMI, energy intake, alcohol, fruit intake and vegetable intake). Sensitivity analysis was conducted in which one study at a time was removed and the remaining studies

Literature identified through PubMed and EMBASE database search (n 5937)

5712 papers excluded on the basis of title or abstract

225 papers retrieved and assessed for eligibility

185 papers excluded for the following reasons:
– Study focused on patients (n 51)
– Not related to outcome (n 103)
– Duplication (n 7)
– No full text (n 24)

40 full papers selected for inclusion

One paper was added after reference search (n 1)

Cross-sectional study (n 10)
Cohort study (n 29)
Nested case–control study (n 2)

Included in highest v. lowest meta-analysis
Total dairy foods and MetS (n 12)
Milk and MetS (n 7)
Yogurt and MetS (n 3)

Included in dose–response meta-analysis
Total dairy foods and MetS (n 9)
Milk and MetS (n 6)
Yogurt and MetS (n 3)

Included in highest v. lowest meta-analysis

Total dairy and hyperglycaemia (n 18)
Milk and hyperglycaemia (n 15)
Yogurt and hyperglycaemia (n 9)

Total dairy foods and abdominal obesity (n 5)
Milk and abdominal obesity (n 7)
Yogurt and abdominal obesity (n 3)

Total dairy foods and high blood pressure (n 9)
Milk and high blood pressure (n 4)

Total dairy foods and hypertriglycaemia (n 5)
Milk and hypertriglycaemia (n 4)

Total dairy foods and low HDL-cholesterol (n 6)
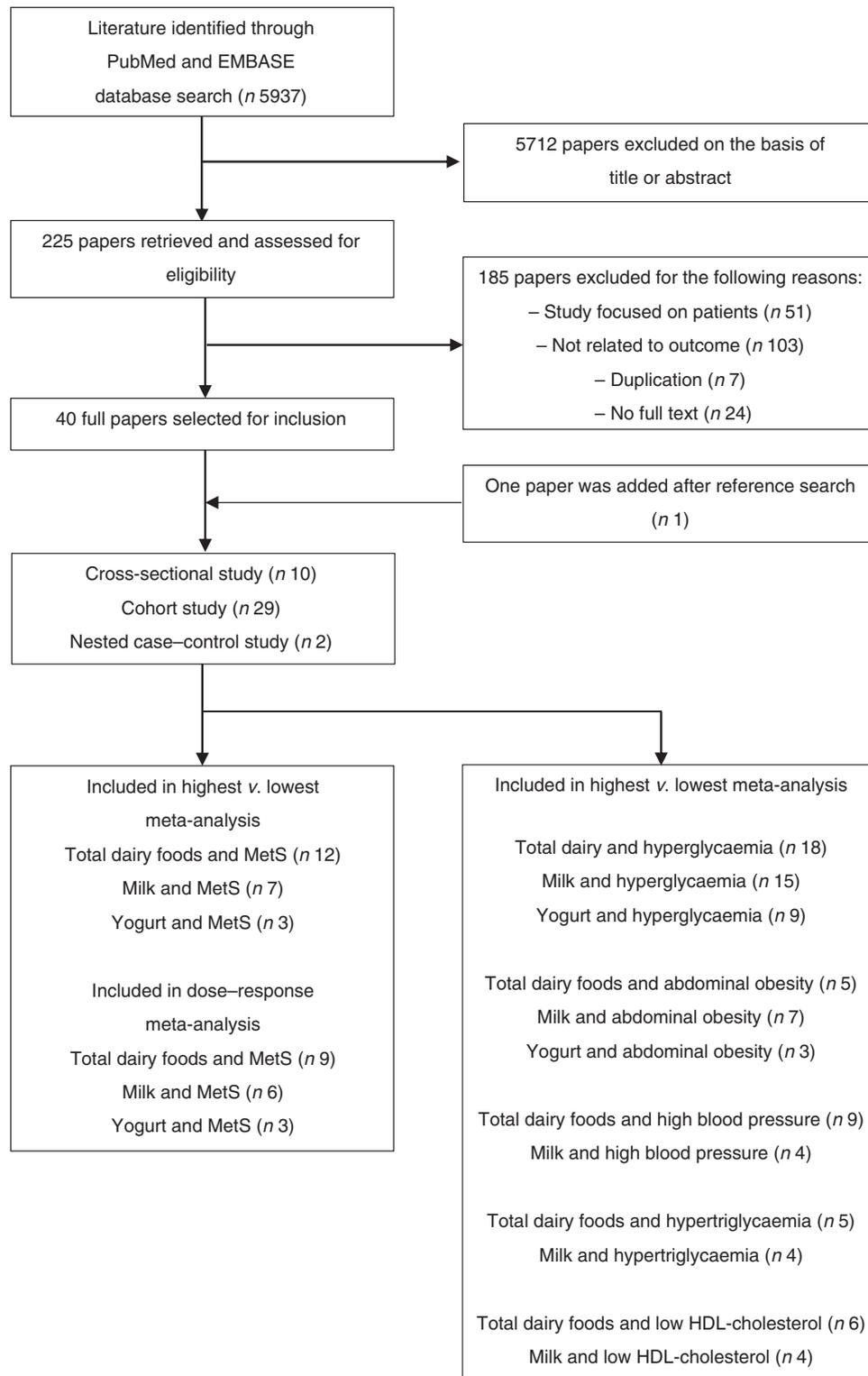Milk and low HDL-cholesterol (n 4)

Fig. 1. Flow chart of literature search for meta-analysis. MetS, metabolic syndrome.

were assessed to evaluate the impact of the single study. To explore the presence of statistical heterogeneity, Higgins $I^{2(40)}$ was conducted, and the I^2 statistic was calculated. The assumption of heterogeneity was considered valid for P values <0·05.

Forest plots were made to visualise and summarise the relationship between total dairy foods, milk or yogurt and the MetS and its components. Publication bias was evaluated by Egger's test[41]. All statistical analysis was performed using Stata/SE 14.2 (STATA). A two-tailed P value <0·05 was considered statistically significant.

Results

Study characteristics

Ten cohort studies[1,7,8,12–14,16,20,21,23] and seven cross-sectional studies[6,9–11,15,19,22] were included in meta-analyses that compared the highest and lowest categories of dairy product intake, and seven cohort studies[1,7,13,14,16,21,23] and six cross-sectional studies[6,10,11,15,19,22] were included in the dose–response meta-analysis on the association between dairy foods (total dairy foods, milk and yogurt) and risk of the MetS (Table 1). Studies on the cheese intake were not included in the meta-analysis because of insufficient number of studies (n 2)[8,14]. Five studies were conducted in Americas, four studies were conducted in Asia, three studies were conducted in Europe and one study was conducted in Oceania. The follow-up range of cohort studies was between 2·3 and 10 years. Two studies[15,16] defined the MetS using the criteria of the International Diabetes Federation[42]. One study[1] defined the MetS based on the criteria of the American Heart Association/National Heart, Lung and Blood Institute[43]. Two studies[10,11] defined the MetS according to the guideline of the National Cholesterol Education Program, Adult Treatment Panel III (NCEP-ATP III)[44]. Three studies[7,19,21] defined the MetS using the criteria of the modified NCEP-ATP III. Five studies[6,13,14,22,23] defined the MetS by the criteria of the Joint Interim Statement[45]. All studies adjusted for multiple confounders of age, smoking and physical activity. Most of the studies adjusted for sex[1,6,7,11,13–16,19,21–23], alcohol intake[6,7,10,13–15,19,21–23] and energy intake[1,6,7,10,11,13,15,16,19,21–23]. Four studies provided the adjusted RR for BMI[11,14,19,22]. For quality assessment of studies, quality score for seven cohort studies included in the dose–response analysis were between 6 and 8, with a mean score of 7. The majority of the cohort studies had good quality scores (five out of seven studies). Quality scores for six cross-sectional studies were between 14 and 17, with an average score of 16. The majority of the cross-sectional studies had good quality scores (four out of six studies). The studies on the relationship between dairy products (total dairy foods, milk and yogurt) and MetS components were described in the online Supplementary Table S1.

Association between dairy food consumption and the metabolic syndrome

A dose–response meta-analysis of nine studies[1,6,7,10,11,13–16] that included five cohort studies, involving 9126 cases and 30 264 participants, and four cross-sectional studies, involving 3680 cases and 16 002 participants, was conducted to explore the association between total dairy food consumption and the MetS. The multivariable-adjusted RR and 95 % CI of the MetS according to one-serving/d increment of dairy food consumption and the MetS are shown in Fig. 2. In a dose–response meta-analysis combining the two types of study design, an increase of 200 g/d of total dairy product intake was associated with a 9 % lower risk of the MetS (RR = 0·91; 95 % CI 0·85, 0·96) with moderate heterogeneity ($I^2 = 51·7$ %, $P = 0·04$).

Six studies[7,10,14,19,21,22] that included three cohort studies involving 2227 cases and 9259 participants and three cross-sectional studies involving 4775 cases and 19 818 participants

examined the relationship between milk consumption and risk of the MetS. In a dose–response analysis, an increase of 200 g/d of milk intake was associated with a 13 % lower risk of the MetS (RR = 0·87; 95 % CI 0·79, 0·95) with no significant heterogeneity ($I^2 = 44·7$ %, $P = 0·11$).

Three studies[14,22,23] including two cohort studies involving 1236 cases and 9931 participants and one cross-sectional study involving 1298 cases and 4862 participants explored the relationship between yogurt intake and the MetS. In a dose–response analysis, the risk of the MetS decreased by 18 % for a 100 g/d increment in yogurt consumption (RR = 0·82; 95 % CI 0·73, 0·91) with no significant heterogeneity ($I^2 = 7·6$ %, $P = 0·34$).

Associations between dairy food consumption and metabolic syndrome components

A meta-analysis of the relationship between dairy food consumption and MetS components is shown in Table 2. In a dose–response analysis, an increase of 200 g/d of total dairy product intake was related to a lower risk of MetS components such as hyperglycaemia (seventeen studies), high blood pressure (ten studies), hypertriacylglycerolaemia (five studies) and low HDL-cholesterol (six studies). An increase of 200 g/d of milk intake (seven studies) was related to a 12 % lower risk of abdominal obesity (RR = 0·88; 95 % CI 0·79, 0·97). An increase of 100 g/d of yogurt intake (nine studies) was associated with a 16 % lower risk of hyperglycaemia (RR = 0·84; 95 % CI 0·70, 0·98).

In a meta-analysis that compared the highest *v.* the lowest category of dairy product intake, the pooled RR for the MetS in the highest category of total dairy product intake (twelve studies) compared with those in the lowest category of total dairy product intake was 0·75 (95 % CI 0·66, 0·84). The pooled RR for the MetS in the highest category of milk (seven studies) and yogurt intake (three studies) compared with those in the lowest category of milk and yogurt were 0·78 (95 % CI 0·69, 0·87) and 0·77 (95 % CI 0·66, 0·88), respectively, with no significant heterogeneity.

In meta-analyses that compared the highest and lowest categories of dairy product intake, total dairy product intake was related to a lower risk of all components of the MetS, and milk intake was related to a lower risk of abdominal obesity (seven studies) and hypertriacylglycerolaemia (four studies). Yogurt intake was related to a lower risk of hyperglycaemia (nine studies) and abdominal obesity (three studies).

Subgroup, meta-regression and sensitivity analyses

The results for subgroup analysis and meta-regression analyses are shown in Table 3. Subgroup analyses for total dairy foods and the MetS found no significant differences in study design. With regard to study location, Americas (RR = 0·93; 95 % CI 0·88, 0·98) and Europe (RR = 0·92; 95 % CI 0·87, 0·98) showed significant inverse associations, whereas Asia and Oceania showed a non-significant inverse association; however, the difference was not significant ($P \geq 0·2$ for all comparisons). With regard to the quality assessment of studies, both good (RR = 0·91; 95 % CI 0·82, 0·99) and others (RR = 0·91; 95 % CI 0·86, 0·96) showed significant inverse associations with no significant difference

Table 1. Characteristics of the studies on the association between dairy products (total dairy foods, milk and yogurt) and the metabolic syndrome included in this meta-analysis (Numbers and percentages, odds ratios, relative risks (RR) and confidence intervals).

References	Study design	Location	Age (years)	n	%	Criteria for the metabolic syndrome	Dietary assessment	Consumption amount	OR or RR	95 % CI	Adjustments	NOS or STROBE score
Total dairy foods												
Azadbakht et al.[11]	Cross-sectional	Iran	18–74	827	56·8	The National Cholesterol Education Program, Adult Treatment Panel III (NCEP-ATP III)	168-Item FFQ and 24-h dietary recall	(servings/d) Q1 (<1·7) Q2 (1·7 < 2·3) Q3 (2·3 < 3·1) Q4 (≥3·1)	1·00 0·96 0·92 0·82	0·69, 1·20 0·84, 1·12 0·63, 0·99	Age, total energy, percentage of energy from fat, BMI, use of blood pressure or oestrogen medication, smoking habits, physical activity, food group intake, Ca, protein	16
Babio et al.[14]	Cohort	Spain	55–80	1868	52·5	Joint Interim Statement (JIS)	137-Item FFQ and 3-d dietary record	(g/d) T1 (≤287) T2 (287–449) T3 (≥450)	1·00 0·80 0·83	0·68, 0·95 0·69, 1·01	Sex, age, leisure time physical activity, BMI, smoking habits, use of hypoglycaemia drugs, use of hypolipidaemic drugs, use of antihypertensive drugs, insulin treatment, vegetable, fruit, legume, cereal, fish, red meat, cookie, olive oil, nut, alcohol, abdominal obesity, hypertriacylglycerolaemia, low HDL-cholesterol, hypertension, high fasting plasma glucose	6
Drehmer et al.[13]	Cohort	Brazil	35–74	9835	54·8	JIS	114-Item FFQ	(servings/d) <1 1–2 >2–4 >4	1·00 0·95 0·91 0·90	0·80, 1·13 0·77, 1·07 0·75, 1·08	Demographic characteristics, age, sex, race, occupational, education, family income, study centre, menopausal status, family history of diabetes, smoking, physical activity, intake of total energy content, fruit, vegetables, refined grains, soda, processed and unprocessed red and white meat, alcohol	7
Fumeron et al.[8]	Cohort	France	30–65	3435	50·2	International Diabetes Federation (IDF)	23-Item questionnaire	(servings/d) >2 v. <1	0·88	0·79, 0·97	Sex, age, smoking, total fat intake, physical activity, mean BMI	9
Huo Yung Kai et al.[6]	Cross-sectional	France	35–64	3078	49·6	JIS	3-d dietary record	(g/1000 kJ) Q1 (0–13·2) Q2 (13·3–23·1) Q3 (23·2–36·3) Q4 (36·4–266)	1·00 0·97 0·92 0·76	0·76, 1·24 0·72, 1·19 0·59, 0·99	Region, sex, age, education level, physical activity, alcohol, smoking, diet, programme national nutrition santé–global score, total daily energy intake	14
Liu et al.[10]	Cross-sectional	USA	≥45	10066	100	NCEP-ATP III	131-Item FFQ and 1-week dietary record	(servings/d) Q1 (<0·91) Q2 (0·91–1·41) Q3 (1·42–1·99) Q4 (2·00–3·00) Q5 (>3·00)	1·00 0·85 0·76 0·77 0·66	0·71, 1·00 0·64, 0·91 0·64, 0·92 0·55, 0·80	Age, randomised treatment assignment, smoking, exercise, parental history of myocardial infarction before age 60 years, dietary intake of total energy content, total fat, cholesterol, protein, alcohol, multivitamins, glycaemic load	15
Louie et al.[16]	Cohort	Australia	≥49	1807		IDF	145-item FFQ	(Median, servings/d) Q1 (0·5) Q2 (1·2) Q3 (1·8) Q4 (3·1)	1·00 1·12 0·62 0·62	0·68, 1·83 0·33, 1·16 0·24, 1·62	Age, sex, smoking, physical activity, dietary glycaemic load, fibre from vegetables, total energy intake, family history of type 2 diabetes, Ca	6
Lutsey et al.[1]	Cohort	USA	45–64	9514	55·9	American Heart Association/National Heart, Lung and Blood Institute (AHA/NHLBI)	66-Item FFQ	(Median, servings/d) Q1 (0·28) Q2 (0·93) Q3 (1·29) Q4 (1·94) Q5 (3·30)	1·00 1·02 1·03 0·96 0·87	0·92, 1·13 0·93, 1·14 0·86, 1·06 0·77, 0·98	Age, sex, race, education, centre, smoking, physical activity, intakes of total energy content, meat, dairy foods, fruits, vegetables, whole grains, refined grains	8

Table 1. Continued

Study	Study design	Country	Age	n	%	Definition	Dietary assessment	Intake	Estimate	95 % CI	Adjustments	Score
Martins et al.[15]	Cross-sectional	Brazil	23–25	2031	51·6	IDF	75-Item FFQ	(portions/d) Q1 (0·0, 0·6) Q2 (0·7, 1·2) Q3 (1·3, 1·7) Q4 (1·8, 2·6) Q5 (2·7, 14·2)	1·00 1·11 1·46 1·26 1·24	0·71, 1·72 0·89, 2·38 0·71, 2·22 0·57, 2·70	Sex, age, education, marital status, smoking, physical activity, intake of total energy content, alcohol, fat, carbohydrates, protein, vegetables, fruit, fruit juice, bread, cereals, rice, meat, fish, eggs, fat, oil, sweets, Ca	16
Pereira et al.[12]	Cohort	USA	18–30	3157		≥2 of the four components: abnormal glucose homoeostasis, obesity, elevated BP and dyslipid	Diet history and 24-h dietary recall	(servings/week) 0 < 10 10 < 16 16 < 24 24 < 35 ≥35	1·00 1·12 0·56 0·42 0·28	0·71, 1·78 0·34, 0·92 0·24, 0·75 0·14, 0·58	Age, sex, race, energy intake per day, study centre, baseline BMI, educational level in years, alcohol, smoking, units of daily physical activity, use of vitamin supplement, dietary fibre, protein	7
Ruidavets et al.[9]	Cross-sectional	France	45–64	912		NCEP-ATP III	3-d dietary record	Q1 Q2 Q3 Q4 Q5	1·00 0·69 0·58 0·46 0·51	0·44, 1·09 0·36, 0·92 0·29, 0·75 0·32, 0·83	Age, centre, physical activity, level of education, smoking, alcohol, drugs for hypertension and dyslipidaemia, energy, dieting, diet quality index	14
Shin et al.[7]	Cohort	Korea	40–69	7240	49·9	The modified NCEP-ATP III criteria with the exception of abdominal obesity	110-item FFQ and 3-d dietary record	(times/week) None 1 2–3 4–6 ≥7	1·00 0·94 0·84 0·75 0·83	0·78, 1·13 0·70, 1·02 0·69, 1·00 0·64, 0·88	Age, sex, physical activity, alcohol, smoking, income, education, total energy intake	8

Milk

Study	Study design	Country	Age	n	%	Definition	Dietary assessment	Intake	Estimate	95 % CI	Adjustments	Score
Babio et al.[14]	Cohort	Spain	55–80	1868	52·5	JIS	137-item FFQ and 3-d dietary record	(Median g/d) T1 (120) T2 (222) T3 (462)	1·00 0·90 0·85	0·77, 1·07 0·70, 1·02	Sex, age, leisure time physical activity, BMI, smoking, use of hypoglycaemia drugs, use of hypolipidaemic drugs, use of antihypertensive drugs, insulin treatment, intake of vegetables, fruit, legumes, cereals, fish, red meat, cookies, olive oil, nuts, alcohol, abdominal obesity, hypertriacylglycerolaemia, low HDL-cholesterol, hypertension, high fasting plasma glucose	6
Damiao et al.[21]	Cohort	Brazil	40–79	151	44·4	Modified NCEP-ATP III	122-item FFQ	(Median, g/d) T1 (12·4) T2 (141·7) T3 (223·7)	1·00 0·92 0·93	2·26, 3·27 0·28, 3·00	Age, sex, physical activity, smoking, education level, alcohol, energy, total fat intake, men only, fried foods	7
Elwood et al.[20]	Cohort	UK	45–59	2375	0	Modified WHO definition	FFQ and 1-week dietary record	Little or none < 1/2 pint 1/2–1 pint > 1Pint	1·00 0·71 0·56 0·38	0·18, 0·78	Age, energy, social class, smoking	5
Kim[22]	Cross-sectional	Korea	≥19	4862	59	JIS	FFQ and 24-h dietary recall	None or rarely ≤2–3/ month ≤4–6/week ≥once/d	1·00 1·12 0·89 0·71	0·91, 1·39 0·73, 1·10 0·55, 0·93	Age, sex, education level, income, smoking, BMI, alcohol, physical activity, energy, fat, Ca, fibre	16
Kwon et al.[19]	Cross-sectional	Korea	≥19	4890	58	The NCEP-ATP III criteria, modified for the Korean abdominal obesity criterion	FFQ and 24-h dietary recall	1st quartile (rarely) 2nd quartile (≤1/week) 3rd quartile (2–6/week) 4th quartile (≥1/d)	1·00 0·86 1·11 0·85	0·69, 1·07 0·87, 1·40 0·68, 1·06	Age, sex, BMI, education level, smoking, physical activity, alcohol, daily energy intake, daily fibre intake	17

Table 1. *Continued*

Liu *et al.*[10]	Cross-sectional	USA	≥45	10066	100	NCEP-ATP III	131-Item FFQ and 1-week dietary record	(servings/d) Q1 (<0·13) Q2 (0·13–0·43) Q3 (0·44–0·93) Q4 (0·94–1·07) Q5 (>1·08)	1·00 0·98 1·07 1·07 0·85	 0·84, 1·16 0·87, 1·32 0·90, 1·27 0·71, 1·02	Age, randomised treatment assignment, smoking, exercise, intake of total energy content, total fat, cholesterol, protein, alcohol, and multivitamins, parental history of myocardial infarction before age 60 years, glycaemic load	15
Shin *et al.*[7]	Cohort	Korea	40–69	7240	49·9	Modified NCEP-ATP III criteria with the exception of abdominal obesity	110-Item FFQ and 3-d dietary record	(times/week) None 1 2–3 4–6 ≥7	1·00 0·92 0·88 0·83 0·79	 0·77, 1·19 0·73, 1·06 0·69, 1·01 0·67, 0·92	Age, sex, physical activity, alcohol, smoking, income, education, energy	8
Yogurt												
Babio *et al.*[14]	Cohort	Spain	55–80	1868	52·5	JIS	137-Item FFQ and 3-d dietary Record	(Median, g/d) T1 (7) T2 (70) T3 (127)	1·00 0·88 0·77	 0·74, 1·04 0·65, 0·91	Sex, age, leisure time physical activity, BMI, smoking, use of hypoglycaemia drugs, use of hypolipidaemic drugs, use of antihypertensive drugs, insulin treatment, intake of vegetables, fruit, legumes, cereals, fish, red meat, cookies, olive oil, nuts, alcohol, abdominal obesity, hypertriacylglycerolaemia, low HDL-cholesterol, hypertension, high fasting plasma glucose	6
Kim[22]	Cross-sectional	Korea	≥19	4862	59	JIS	FFQ and 24-h dietary recall	None or rarely ≤ 2–3/ month ≤ 4–6/week ≥once/d	1·00 0·88 0·77 0·71	 0·73, 1·06 0·62, 0·95 0·48, 1·05	Age, sex, education level, income, smoking, BMI, alcohol, physical activity, energy, fat, Ca, fibre	16
Sayon-Orea *et al.*[23]	Cohort	Spain	20–90	8063	658	JIS	136-Item FFQ	(g/week) 0–250 250 < 875 ≥875	1·00 1·22 0·84	 0·92, 1·62 0·60, 1·18	Age, sex, weight, energy, alcohol, soft drinks, red meat, french fries, fast food, adherence to the Mediterranean diet or another diet, physical activity, sedentary behaviour, hours sitting, smoking, snacking between meals	7

NOS, Newcastle–Ottawa quality assessment; STROBE, Strengthening the Reporting of Observational studies in Epidemiology statement; BP, blood pressure; NCEP-ATP III, National Cholesterol Education Program, Adult Treatment Panel III.
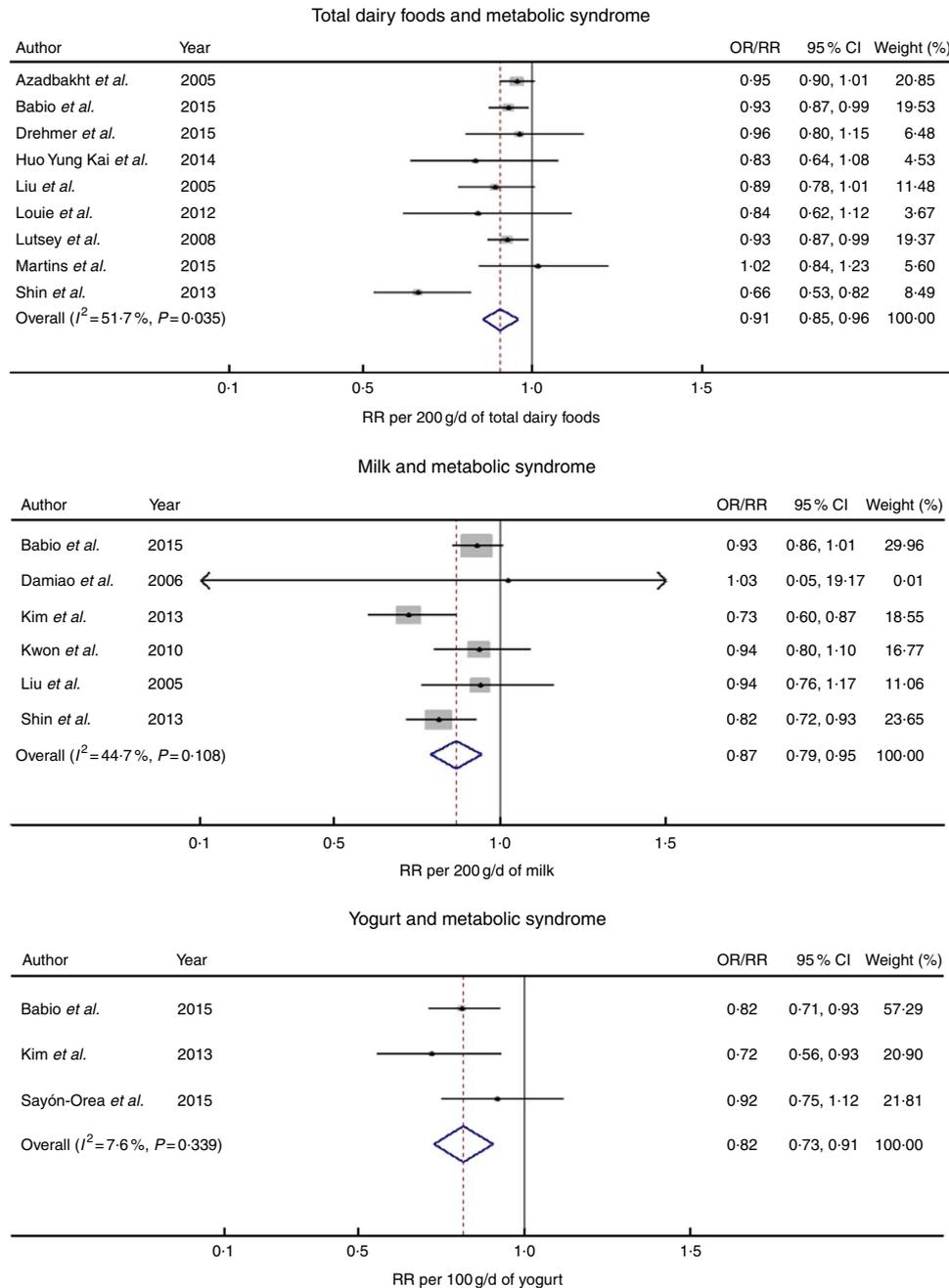
Fig. 2. The forest plot for the linear dose–response relationship between dairy food consumption (per increment of g/d) by subtype and the metabolic syndrome. RR, relative risk.

($P = 0.50$). With regard to fat content of dairy foods, whole-fat dairy product intake showed a significant inverse association (RR = 0.78; 95 % CI 0.61, 0.96) with no significant heterogeneity ($I^2 = 29$ %, $P = 0.24$), whereas low-fat dairy foods showed no association. Only one study that provided the RR adjusted for fruit and vegetable intake showed an inverse association (RR = 0.94; 95 % CI 0.91, 0.97) compared with the pooled RR of the other studies (RR = 0.80; 95 % CI 0.68, 0.92), and the results of the meta-regression analysis showed that the difference was significant ($P = 0.01$). In addition, meta-regression analyses showed that adjustment for alcohol, BMI or energy intake did not contribute to heterogeneity ($P \geq 0.2$ for all comparisons). In

a sensitivity analysis, the pooled RR were in the range of 0.89 (95 % CI 0.83, 0.95)–0.93 (95 % CI 0.90, 0.96). When one study with no adjustment for dietary factors[7] (e.g. adjustments for dietary factors such as fat, protein, fibre, Ca, fruit, vegetable, meat, fish and grain were made in other studies) was excluded, the significance for heterogeneity disappeared ($P = 0.84$), and similar results were obtained (RR = 0.93; 95 % CI 0.90, 0.96).

Subgroup analyses for milk intake and the MetS found no significant differences in study location ($P \geq 0.2$ for all comparisons). With regard to study design, a cohort study design showed a significant inverse relationship (RR = 0.88; 95 % CI 0.80, 0.97), whereas a cross-sectional study showed a not

Table 2. Meta-analyses for dairy food consumption by subtype and the metabolic syndrome and its components
(Relative risks and 95 % confidence intervals)

	Total dairy foods					Milk					Yogurt				
	Pooled RR	95 % CI	n	Heterogeneity I² (%)	P	Pooled RR	95 % CI	n	Heterogeneity I² (%)	P	Pooled RR	95 % CI	n	Heterogeneity I² (%)	P
Dose–response meta-analysis	200 g/d					200 g/d					100 g/d				
Metabolic syndrome	0·91	0·85, 0·96	9	51·7	0·04	0·87	0·79, 0·95	6	44·7	0·11	0·82	0·73, 0·91	3	7·6	0·34
Hyperglycaemia	0·94	0·91, 0·97	17	24·3	0·17	0·90	0·79, 1·01	14	88·6	0·00	0·84	0·70, 0·98	9	81·5	0·00
Abdominal obesity	0·90	0·79, 1·00	5	83·3	0·00	0·88	0·79, 0·97	7	56·8	0·03					
High blood pressure	0·94	0·91, 0·97	10	8·0	0·37	0·97	0·91, 1·03	5	0·0	0·90					
Hypertriacylglycerolaemia	0·95	0·92, 0·99	5	0·0	0·74	0·94	0·82, 1·07	4	57·5	0·07					
Low HDL-cholesterol	0·94	0·91, 0·98	6	0·0	0·99	0·95	0·85, 1·05	4	43·7	0·15					
Highest v. lowest meta-analysis															
Metabolic syndrome	0·75	0·66, 0·84	12	71·8	0·00	0·78	0·69, 0·87	7	36·1	0·15	0·77	0·66, 0·88	3	0·0	0·82
Hyperglycaemia	0·84	0·78, 0·89	18	27·8	0·13	0·90	0·80, 1·00	15	73·9	0·00	0·80	0·67, 0·93	9	62·1	0·01
Abdominal obesity	0·76	0·61, 0·92	5	55·9	0·06	0·83	0·73, 0·92	7	46·2	0·08	0·74	0·63, 0·85	3	0·0	0·90
High blood pressure	0·87	0·80, 0·95	9	0·0	0·55	0·92	0·82, 1·02	4	0·0	0·84					
Hypertriacylglycerolaemia	0·87	0·78, 0·95	5	0·0	0·54	0·90	0·81, 0·98	4	0·0	0·62					
Low HDL-cholesterol	0·90	0·81, 0·99	6	0·0	0·78	0·89	0·75, 1·04	4	72·8	0·01					

Table 3. Subgroup analyses of studies on the association of dairy food (total dairy foods and milk) consumption and risk of the metabolic syndrome (MetS) included in dose–response analysis
(Relative risks and 95 % confidence intervals)

Studies	No. of studies	RR	95 % CI	P*
Total dairy foods and the MetS				
All studies	9	0·91	0·85, 0·96	
Study design				
Cohort	5	0·88	0·79, 0·96	0·37
Cross-sectional	4	0·94	0·90, 0·99	
Study location				
Americas†	4	0·93	0·88, 0·98	
Asia	2	0·81	0·53, 1·10	0·18‡
Europe	2	0·92	0·87, 0·98	0·54‡
Oceania	1	0·84	0·62, 1·12	0·45‡
Quality assessment				
Good	5	0·91	0·82, 0·99	0·50
Others	4	0·91	0·86, 0·96	
Fat content				
Whole fat	4	0·78	0·61, 0·96	0·12
Low fat	4	0·95	0·84, 1·07	
Adjustment for confounders				
Alcohol				
Yes	6	0·88	0·79, 0·97	0·34
No	3	0·94	0·90, 0·98	
BMI				
Yes	2	0·94	0·90, 0·98	0·23
No	7	0·88	0·79, 0·96	
Energy intake				
Yes	8	0·90	0·83, 0·96	0·95
No	1	0·93	0·87, 0·99	
Fruit, vegetable intake				
Yes	5	0·94	0·91, 0·97	0·01
No	4	0·80	0·68, 0·92	
Milk and the MetS				
All studies	6	0·87	0·79, 0·95	
Study design				
Cohort	3	0·88	0·80, 0·97	0·73
Cross-sectional	3	0·86	0·71, 1·01	
Study location				
Americas†	1	1·03	0·05, 19·17	
Asia	3	0·82	0·71, 0·93	0·16§
Europe	2	0·93	0·86, 1·00	0·53§
Quality assessment				
Good	4	0·82	0·73, 0·92	0·05
Others	2	0·93	0·86, 1·00	
Adjustment for confounders				
BMI				
Yes	3	0·87	0·74, 1·00	0·37
No	3	0·84	0·75, 0·94	
Energy intake				
Yes	5	0·84	0·75, 0·93	0·10
No	1	0·93	0·86, 1·01	
Fruit, vegetable intake				
Yes	1	0·93	0·86, 1·01	0·10
No	5	0·84	0·75, 0·93	

* P values for heterogeneity between subgroups with meta-regression analysis.
† Including USA and Brazil.
‡ P value for difference in RR of total dairy food consumption for Asia v. Americas, Europe v. Americas, Oceania v. Americas.
§ P value for difference in RR of milk consumption for Asia v. Americas, Europe v. Americas.

significant relationship; however, the difference between them was not significant (P = 0·73). With regard to the quality assessment of studies, studies with good quality (RR = 0·82; 95 % CI 0·73, 0·92) showed significant inverse associations, whereas others showed a non-significant inverse association; however, the difference was not significant (P = 0·05).

According to adjustment factors, no significant differences with regard to BMI, energy intake and fruit and vegetable intake were found based on the results of meta-regression analyses ($P \geq 0.1$ for all comparisons). In a sensitivity analysis for milk intake and the MetS, the pooled RR were in the range of 0.84 (95 % CI 0.75, 0.93)–0.90 (95 % CI 0.85, 0.96).

Subgroup analysis for yogurt intake and the MetS were not conducted because only three studies were found.

Publication bias

There was no indication of publication bias for a dose–response meta-analysis of total dairy food consumption and the MetS (Egger's $P = 0.12$), milk intake and the MetS (Egger's $P = 0.20$) or yogurt intake and the MetS (Egger's $P = 0.93$).

Discussion

This meta-analysis of epidemiological studies including prospective cohort studies and cross-sectional studies showed an inverse relationship between specific types of dairy food consumption and incidence or prevalence of the MetS. In a dose–response meta-analysis, a one-serving increment of total dairy food consumption was associated with a 9 % lower risk of the MetS. In addition, a one-serving increment/d in milk and yogurt consumption was related to a 13 and 18 % lower risk of the MetS, respectively. Dairy food consumption was associated with individual components of the MetS as well as the MetS. Total dairy food consumption was inversely associated with the components of the MetS such as hyperglycaemia, high blood pressure, hypertriacylglycerolaemia and low HDL-cholesterol. A one-serving increment/d of milk consumption was related to a 12 % lower risk of abdominal obesity, respectively, and a one-serving increment/d in yogurt consumption was related to a 16 % lower risk of hyperglycaemia. This inverse association did not vary in terms of study design, study location or adjustment factors. These results suggest that specific types of dairy food consumption such as milk and yogurt as well as total dairy product intake were inversely linked to the MetS and its components.

These results are consistent with the findings from previous studies showing the effects of consumption of total dairy foods or specific types of dairy foods on metabolic risk factors. A meta-analysis of cohort studies showed an inverse association between total dairy food consumption and the MetS[18]. Increased total dairy food consumption has also been reported to reduce abdominal obesity in a clinical trial[46]. Another meta-analysis of cohort studies showed an inverse association between total dairy food consumption and the risk of hypertension[47]. Furthermore, a high intake of milk and yogurt consumption was inversely related to risk of the MetS and hypertriacylglycerolaemia in a cohort study[48]. A systematic review of intervention studies and a multi-centre study reported that dairy foods improved insulin sensitivity[49] and lipid profiles[50].

Potential mechanisms explaining the beneficial effect of dairy foods such as milk and yogurt on metabolic risk factors have been suggested. Milk and yogurt have several nutrients such as Ca and dairy proteins, which are known to have favourable effects on health.Ca, which is abundant in milk and yogurt, combines with fatty acids and bile acids in the intestine, thereby increasing faecal fat excretion and/or inhibiting fat reabsorption[51]. This can result in an improved ratio of HDL-cholesterol: LDL-cholesterol[52]. In addition, Ca might affect lipid profiles by regulating intracellular Ca concentration. Well-regulated serum Ca level through the intake of Ca from dairy foods decreases intracellular Ca level and results in the inhibition of fatty acid synthesis and stimulation of lipolysis[53]. Milk proteins, such as whey protein and casein, might be responsible for the beneficial effects of dairy foods on blood pressure as they can regulate blood pressure via inhibition of angiotensin I-converting enzyme and, as a result, by reducing angiotensin II, a potent vasoconstrictor[54]. In addition, specific amino acids from whey protein, in particular branched-chain amino acids and dairy protein-derived peptides, might play an important role in the regulation of insulinaemia, blood pressure, dyslipidaemia and fat accumulation[55,56]. Specifically, yogurt consumption was associated with a lower risk of hyperglycaemia. This phenomenon could be partly explained by the fact that yogurt is a good source of vitamin K_2, which is synthesised by bacteria and there only present in fermented dairy foods[57]. Vitamin K_2 has recently been linked to a reduced risk of type 2 diabetes[58]. The combined and synergic effects of various nutrients in dairy foods might contribute to favourable effects on the MetS risk factors.

Interestingly, low-fat dairy foods were not significantly linked to risk of the MetS in the subgroup analysis. Low-fat dairy product intake is associated with reduced saturated fat intake, which could be protective against the components of the MetS such as lipid profiles and insulin resistance[16]. Possibly, the favourable effect of low-fat dairy foods on the MetS might be diminished because people consuming low-fat dairy foods increased fat or carbohydrate intake from the diet, which may affect metabolic risk factors. A recent clinical study is in-line with our findings. Daily intake of low-fat dairy products for 8 weeks did not improve metabolic risk factors related to the MetS except for a slight decrease in systolic blood pressure in obese subjects[59].

The present meta-analysis has several strengths. To the best of our knowledge, this is the first meta-analysis of epidemiological studies to investigate the relationship between specific types of dairy food consumption and the risk of the MetS and its components. In addition, this study assessed a linear association between the consumption of individual dairy foods and the risk of the MetS using dose–response meta-analysis. All studies included in the meta-analysis were of good quality according to quality assessment, and most of the studies adjusted for critical confounders of the MetS such as age, sex, BMI, energy intake, alcohol intake, smoking and physical activity.

The present study has some limitations. This meta-analysis only included observational studies; thus, there is a possibility of residual or unmeasured confounding factors, although we used multivariable RR and adjusted for potential confounders, and the subgroup analyses showed no significant difference in terms of adjustment factors (study design, study location, BMI,

alcohol, energy intake). Second, different criteria were used to diagnose the MetS, and the studies included in this meta-analysis used different methods for dietary assessment; the use of different criteria or method might affect the strength of the link between dairy food consumption and risk of the MetS and its components. Third, we could not conduct a meta-analysis for various types of dairy foods such as cheese because of the lack of studies conducted.

In conclusion, the results from this dose–response meta-analysis of prospective cohort studies and cross-sectional studies showed that individual dairy food consumption such as milk and yogurt as well as total dairy food consumption was inversely associated with risk of the MetS and its components. A meta-analysis on randomised clinical trials should be conducted to provide strong evidence for the relationship between individual dairy food consumption and risk of the MetS and its components.

Acknowledgements

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114518001460

References

1. Lutsey PL, Steffen LM & Stevens J (2008) Dietary intake and the development of the metabolic syndrome: the Atherosclerosis Risk in Communities study. *Circulation* **117**, 754–761.

2. Mozumdar A & Liguori G (2011) Persistent increase of prevalence of metabolic syndrome among U.S. adults: NHANES III to NHANES 1999–2006. *Diabetes Care* **34**, 216–219.

3. Nestel P, Lyu R, Low LP, et al. (2007) Metabolic syndrome: recent prevalence in East and Southeast Asian populations. *Asia Pac J Clin Nutr* **16**, 362–367.

4. Kaduka LU, Kombe Y, Kenya E, et al. (2012) Prevalence of metabolic syndrome among an urban population in Kenya. *Diabetes Care* **35**, 887–893.

5. Chung SJ, Lee Y, Lee S, et al. (2015) Breakfast skipping and breakfast type are associated with daily nutrient intakes and metabolic syndrome in Korean adults. *Nutr Res Pract* **9**, 288–295.

6. Huo Yung Kai S, Bongard V, Simon C, et al. (2014) Low-fat and high-fat dairy products are differently related to blood lipids and cardiovascular risk score. *Eur J Prev Cardiol* **21**, 1557–1567.

7. Shin H, Yoon YS, Lee Y, et al. (2013) Dairy product intake is inversely associated with metabolic syndrome in Korean adults: Anseong and Ansan cohort of the Korean Genome and Epidemiology Study. *J Korean Med Sci* **28**, 1482–1488.

8. Fumeron F, Lamri A, Abi Khalil C, et al. (2011) Dairy consumption and the incidence of hyperglycemia and the metabolic syndrome: results from a french prospective study, data from the Epidemiological Study on the Insulin Resistance Syndrome (DESIR). *Diabetes Care* **34**, 813–817.

9. Ruidavets JB, Bongard V, Dallongeville J, et al. (2007) High consumptions of grain, fish, dairy products and combinations of these are associated with a low prevalence of metabolic syndrome. *J Epidemiol Community Health* **61**, 810–817.

10. Liu S, Song Y, Ford ES, et al. (2005) Dietary calcium, vitamin D, and the prevalence of metabolic syndrome in middle-aged and older U.S. women. *Diabetes Care* **28**, 2926–2932.

11. Azadbakht L, Mirmiran P, Esmaillzadeh A, et al. (2005) Dairy consumption is inversely associated with the prevalence of the metabolic syndrome in Tehranian adults. *Am J Clin Nutr* **82**, 523–530.

12. Pereira MA, Jacobs DR Jr, Van Horn L, et al. (2002) Dairy consumption, obesity, and the insulin resistance syndrome in young adults: the CARDIA Study. *JAMA* **287**, 2081–2089.

13. Drehmer M, Pereira MA, Schmidt MI, et al. (2016) Total and full-fat, but not low-fat, dairy product intakes are inversely associated with metabolic syndrome in adults. *J Nutr* **146**, 81–89.

14. Babio N, Becerra-Tomas N, Martinez-Gonzalez MA, et al. (2015) Consumption of yogurt, low-fat milk, and other low-fat dairy products is associated with lower risk of metabolic syndrome incidence in an elderly Mediterranean population. *J Nutr* **145**, 2308–2316.

15. Martins ML, Kac G, Silva RA, et al. (2015) Dairy consumption is associated with a lower prevalence of metabolic syndrome among young adults from Ribeirao Preto, Brazil. *Nutrition* **31**, 716–721.

16. Louie JC, Flood VM, Rangan AM, et al. (2013) Higher regular fat dairy consumption is associated with lower incidence of metabolic syndrome but not type 2 diabetes. *Nutr Metab Cardiovasc Dis* **23**, 816–821.

17. Chen GC, Szeto IM, Chen LH, et al. (2015) Dairy products consumption and metabolic syndrome in adults: systematic review and meta-analysis of observational studies. *Sci Rep* **5**, 14606.

18. Kim Y & Je Y (2016) Dairy consumption and risk of metabolic syndrome: a meta-analysis. *Diabet Med* **33**, 428–440.

19. Kwon HT, Lee CM, Park JH, et al. (2010) Milk intake and its association with metabolic syndrome in Korean: analysis of the third Korea National Health and Nutrition Examination Survey (KNHANES III). *J Korean Med Sci* **25**, 1473–1479.

20. Elwood PC, Pickering JE & Fehily AM (2007) Milk and dairy consumption, diabetes and the metabolic syndrome: the Caerphilly prospective study. *J Epidemiol Community Health* **61**, 695–698.

21. Damiao R, Castro TG, Cardoso MA, et al. (2006) Dietary intakes associated with metabolic syndrome in a cohort of Japanese ancestry. *Br J Nutr* **96**, 532–538.

22. Kim J (2013) Dairy food consumption is inversely associated with the risk of the metabolic syndrome in Korean adults. *J Hum Nutr Diet* **26**, Suppl. 1, 171–179.

23. Sayon-Orea C, Bes-Rastrollo M, Marti A, et al. (2015) Association between yogurt consumption and the risk of metabolic syndrome over 6 years in the SUN study. *BMC Public Health* **15**, 170.

24. Struijk EA, Heraclides A, Witte DR, et al. (2013) Dairy product intake in relation to glucose regulation indices and risk of type 2 diabetes. *Nutr Metab Cardiovasc Dis* **23**, 822–828.

British Journal of Nutrition

25. Engberink MF, Geleijnse JM, de Jong N, *et al.* (2009) Dairy intake, blood pressure, and incident hypertension in a general Dutch population. *J Nutr* **139**, 582–587.

26. Engberink MF, Hendriksen MA, Schouten EG, *et al.* (2009) Inverse association between dairy intake and hypertension: the Rotterdam Study. *Am J Clin Nutr* **89**, 1877–1883.

27. Heraclides A, Mishra GD, Hardy RJ, *et al.* (2012) Dairy intake, blood pressure and incident hypertension in a general British population: the 1946 birth cohort. *Eur J Nutr* **51**, 583–591.

28. Wells G, Shea B, O'Connell D, *et al.* (2017) The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. http://www.ohrica/programs/clinical_epidemiology/oxford.asp. (accessed April 2017).

29. Von Elm E, Altman DG, Egger M, *et al.* (2014) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. *Int J Surg* **12**, 1495–1499.

30. DerSimonian R & Laird N (1986) Meta-analysis in clinical trials. *Control Clin Trials* **7**, 177–188.

31. Crichton GE & Alkerwi A (2014) Whole-fat dairy food intake is inversely associated with obesity prevalence: findings from the Observation of Cardiovascular Risk Factors in Luxembourg study. *Nutr Res* **34**, 936–943.

32. Grantham NM, Magliano DJ, Hodge A, *et al.* (2013) The association between dairy food intake and the incidence of diabetes in Australia: the Australian Diabetes Obesity and Lifestyle Study (AusDiab). *Public Health Nutr* **16**, 339–345.

33. Liu S, Choi HK, Ford E, *et al.* (2006) A prospective study of dairy intake and the risk of type 2 diabetes in women. *Diabetes Care* **29**, 1579–1584.

34. Choi HK, Willett WC, Stampfer MJ, *et al.* (2005) Dairy consumption and risk of type 2 diabetes mellitus in men: a prospective study. *Arch Intern Med* **165**, 997–1003.

35. Funtikova AN, Subirana I, Gomez SF, *et al.* (2015) Soft drink consumption is positively associated with increased waist circumference and 10-year incidence of abdominal obesity in Spanish adults. *J Nutr* **145**, 328–334.

36. Satija A, Agrawal S, Bowen L, *et al.* (2013) Association between milk and milk product consumption and anthropometric measures in adult men and women in India: a cross-sectional study. *PLOS ONE* **8**, e60739.

37. Kirii K, Mizoue T, Iso H, *et al.* (2009) Calcium, vitamin D and dairy intake in relation to type 2 diabetes risk in a Japanese cohort. *Diabetologia* **52**, 2542–2550.

38. Greenland S & Longnecker MP (1992) Methods for trend estimation from summarized dose–response data, with applications to meta-analysis. *Am J Epidemiol* **135**, 1301–1309.

39. Orsini N, Bellocco R & Greenland S (2006) Generalized least squares for trend estimation of summarized dose–response data. *Stata J* **6**, 40–57.

40. Higgins JP & Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. *Stat Med* **21**, 1539–1558.

41. Egger M, Davey Smith G, Schneider M, *et al.* (1997) Bias in meta-analysis detected by a simple, graphical test. *BMJ* **315**, 629–634.

42. International Diabetes Federation Clinical Guidelines Task Force (2006) Global guideline for type 2 diabetes: recommendations for standard, comprehensive, and minimal care. *Diabet Med* **23**, 579–593.

43. Grundy SM, Cleeman JI, Daniels SR, *et al.* (2005) Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation* **112**, 2735–2752.

44. National Cholesterol Education Program Expert Panel on Detection Evaluation Treatment of High Blood Cholesterol in Adults (2002) Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. *Circulation* **106**, 3143–3421.

45. Alberti KG, Eckel RH, Grundy SM, *et al.* (2009) Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 120, 1640–1645.

46. Zemel MB, Richards J, Milstead A, *et al.* (2005) Effects of calcium and dairy on body composition and weight loss in African-American adults. *Obes Res* **13**, 1218–1225.

47. Ralston RA, Lee JH, Truby H, *et al.* (2012) A systematic review and meta-analysis of elevated blood pressure and consumption of dairy foods. *J Hum Hypertens* **26**, 3–13.

48. Kim D & Kim J (2017) Dairy consumption is associated with a lower incidence of the metabolic syndrome in middle-aged and older Korean adults: the Korean Genome and Epidemiology Study (KoGES). *Br J Nutr* **117**, 148–160.

49. Turner KM, Keogh JB & Clifton PM (2015) Dairy consumption and insulin sensitivity: a systematic review of short- and long-term intervention studies. *Nutr Metab Cardiovasc Dis* **25**, 3–8.

50. Abdullah MM, Cyr A, Lepine MC, *et al.* (2015) Recommended dairy product intake modulates circulating fatty acid profile in healthy adults: a multi-centre cross-over study. *Br J Nutr* **113**, 435–444.

51. Boon N, Hul GB, Stegen JH, *et al.* (2007) An intervention study of the effects of calcium intake on faecal fat excretion, energy metabolism and adipose tissue mRNA expression of lipid-metabolism related proteins. *Int J Obes (Lond)* **31**, 1704–1712.

52. Reid IR, Mason B, Horne A, *et al.* (2002) Effects of calcium supplementation on serum lipid concentrations in normal older women: a randomized controlled trial. *Am J Med* **112**, 343–347.

53. Welberg JW, Monkelbaan JF, de Vries EG, *et al.* (1994) Effects of supplemental dietary calcium on quantitative and qualitative fecal fat excretion in man. *Ann Nutr Metab* **38**, 185–191.

54. Choi J, Sabikni L & Hassan A (2012) Bioactive peptides in dairy products. *Int J Dairy Technol* **65**, 1–12.

55. Nilsson M, Holst JJ & Bjorck IM (2007) Metabolic effects of amino acid mixtures and whey protein in healthy subjects: studies using glucose-equivalent drinks. *Am J Clin Nutr* **85**, 996–1004.

56. Ricci-Cabello I, Herrera MO & Artacho R (2012) Possible role of milk-derived bioactive peptides in the treatment and prevention of metabolic syndrome. *Nutr Rev* **70**, 241–255.

57. Schurgers LJ & Vermeer C (2000) Determination of phylloquinone and menaquinones in food. Effect of food matrix on circulating vitamin K concentrations. *Haemostasis* **30**, 298–307.

58. Beulens JW, van der AD, Grobbee DE, *et al.* (2010) Dietary phylloquinone and menaquinones intakes and risk of type 2 diabetes. *Diabetes Care* **33**, 1699–1705.

59. van Meijl LE & Mensink RP (2011) Low-fat dairy consumption reduces systolic blood pressure, but does not improve other metabolic risk parameters in overweight and obese subjects. *Nutr Metab Cardiovasc Dis* **21**, 355–361.