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Review Article

Associations of vegetable and fruit consumption with metabolic syndrome. A meta-analysis of observational studies

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Abstract
Objective: To examine the associations of vegetable and/or fruit consumption with metabolic syndrome (MetS).
Design: Meta-analysis of observational studies.
Setting: The electronic databases of PubMed, Web of Science and EMBASE were searched up to September 2017 for observational studies concerning the associations of vegetable and/or fruit consumption with MetS. The pooled relative risk (RR) of MetS for the highest *v.* the lowest category of vegetable and/or fruit consumption, as well as their corresponding 95 % CI, were calculated.
Results: A total of twenty-six observational studies (twenty cross-sectional, one case–control and five cohort studies) were included in the meta-analysis. Specifically, sixteen studies were related to vegetable consumption and the overall multivariable-adjusted RR evidenced a negative association between vegetable consumption and MetS (RR = 0·89, 95 % CI 0·85, 0·93; $P < 0·001$). For fruit consumption, sixteen studies were included and the overall multivariable-adjusted RR demonstrated that fruit consumption was inversely associated with MetS (RR = 0·81, 95 % CI 0·75, 0·88; $P < 0·001$). For vegetable and fruit consumption, eight studies were included; the overall multivariable-adjusted RR showed that vegetable and fruit consumption was also negatively associated with MetS (RR = 0·75, 95 % CI 0·63, 0·90; $P = 0·002$).
Conclusions: The existing evidence suggests that vegetable and/or fruit consumption is negatively associated with MetS. More well-designed prospective cohort studies are needed to elaborate the concerned issues further.

Keywords
Vegetables
Fruits
Metabolic syndrome
Meta-analysis
Observational studies

Metabolic syndrome (MetS) is associated with the development of CVD[1]. MetS involves at least three of the five following metabolic alterations: elevated waist circumference, high serum TAG, low HDL cholesterol, elevated fasting plasma glucose and elevated blood pressure[2]. With its prevalence increasing exponentially in recent decades, MetS has been regarded as an important public health issue in the 21st century, affecting about 25 % of the population in developed countries in parallel with obesity and diabetes[3]. Recently, increasing evidence has shown that alcohol consumption[4], soft drink intake[5] and coffee and tea consumption[6] are closely associated with MetS. Therefore, dietary factors are considered to play an important role in MetS[7].

As important sources for a wide range of beneficial nutrients and non-nutrient substances, fruits and vegetables are rich in fibre, vitamins (particularly A, B and C), minerals (Se and K), antioxidants (carotenoids and tocopherols) and phytochemicals (flavonoids, glucosinolates and isothiocyanates)[8]. A survey report, which was based on a sample extracted from fifty-two low- and middle-income countries, showed that 77·6 % of men and 78·4 % of women had daily fruit and vegetable intake lower than 400 g (the minimum intake recommended by the WHO)[9]. Low intake of fruits and vegetables is deemed a risk factor for many health problems, such as cancer, CVD, stroke and all-cause mortality[10]. The consumption of vegetables and fruits should also be considered with regard to MetS. Vitamin C and fibre, which are two of the primary constituents in vegetables and fruits, are believed conducive to the control of MetS[11–14]. In addition, antioxidants and anti-inflammatory components from fruits and vegetables are also considered to be beneficial for MetS[15]. Therefore, it is natural to speculate

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that vegetable and/or fruit consumption is inversely associated with MetS. To our best knowledge, the effect of vegetable and/or fruit intake on MetS has been investigated by numerous epidemiological studies[7,16–40], but conclusions are still controversial. In view of this, the present meta-analysis of observational studies aimed to further examine the associations of vegetable and/or fruit consumption with MetS. It was hypothesized that vegetable and/or fruit consumption would be inversely associated with MetS.

Materials and methods

Search strategy

The current meta-analysis was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines[41]. The electronic databases of PubMed, Web of Science and EMBASE were searched up to September 2017, using a series of logic combinations of keywords and in-text words that are related to MetS ('metabolic syndrome', 'metabolism syndrome'), vegetables and fruits ('vegetable', 'vegetables', 'fruit', 'fruits'). No language restrictions were set in the search strategy. We first screened the title and abstract of all the articles to identify eligible studies and then read the full article to include eligible studies. Moreover, the reference lists from retrieved articles were reviewed to identify additional studies. The corresponding author of the potential relevant study was contacted if the full text was not available.

Study selection

The title, abstract and full text of all retrieved studies were reviewed by two researchers (Y.Z. and D.Z.Z.) independently. Disagreements were resolved by discussion and mutual consultation. The included studies were required to meet the following criteria: (i) observational studies in the general population; (ii) the exposure of interest was vegetable and/or fruit consumption; (iii) the study outcome included MetS; and (iv) hazard ratio (HR), relative risk (RR) or odds ratio (OR) and 95 % CI were reported. The exclusion criteria were as follows: (i) duplicated or irrelevant articles; (ii) reviews, letters or case reports; (iii) randomized controlled trials; and (iv) non-human studies.

Data extraction

Data extraction was conducted by two independent reviewers (Y.Z. and D.Z.Z.) and disagreements were resolved by consensus. The following information was collected: first author, year of publication, location, age and gender of the study population, sample size, study design, adjustments, exposure, exposure assessment and diagnostic criteria of MetS. The corresponding effect estimates adjusted for the maximum number of confounding variables with corresponding 95 % CI for the highest *v.* lowest level were extracted. For the studies that did not report direct effect estimates, we calculated pooled effect estimates using the natural logarithm of the RR and 95 % CI.

Quality assessment

Quality assessment was conducted according to the Newcastle–Ottawa criteria for non-randomized studies[42], which are based on three broad perspectives: (i) the selection process of study cohorts, (ii) the comparability among different cohorts and (iii) the identification of either the exposure or outcome of study cohorts. Disagreements with respect to the methodological quality were resolved by discussion and mutual consultation.

Statistical analyses

The RR was considered as the common measure of the associations of vegetable and fruit consumption with MetS, and OR and HR were directly converted into RR. The homogeneity of effect size across trials was tested by Q statistics ($P < 0{\cdot}05$ was considered heterogeneous). The I^2 statistic, which measures the percentage of the total variation across studies due to heterogeneity, was also examined ($I^2 > 50\,\%$ was considered heterogeneity). If significant heterogeneity was observed among studies, the random-effects model was used; otherwise, the fixed-effects model was acceptable. Begg's tests were performed to assess the publication bias[43]. Meta-regression was performed to explore the potentially important covariates that might exert substantial impacts on between-study heterogeneity[44]. Subgroup analyses were performed by gender, study design, geographical region, age of the population, diagnostic criteria of MetS, sample size and type of vegetable (only for vegetables). In addition, a sensitivity analysis was also conducted to determine whether an individual study affected the pooled result. All statistical analyses were performed using the statistical software package STATA version 11.0. A P value $\leq 0{\cdot}05$ was accepted as statistically significant, unless otherwise specified.

Results

Study identification and selection

Figure 1 presents the detailed flow diagram of articles included in the present meta-analysis. A total of 2005 potentially relevant articles (PubMed, *n* 561; EMBASE, *n* 841; Web of Science, *n* 603) were retrieved during the initial literature search. After eliminating 809 duplicated articles, 1169 articles were screened by title and abstract, leading to initial exclusion of 647 irrelevant studies. Then, 304 reviews, case reports or letters, 146 non-human studies, seventy-two randomized control trials studies and one articles without full-text accessibility were removed. Eventually, a total of twenty-six observational studies were selected for the current meta-analysis[7,16–40].

Study characteristics

Table 1 shows the main characteristics of the included studies. These studies were published between 2007 and 2017, and include twenty cross-sectional, one case–control and

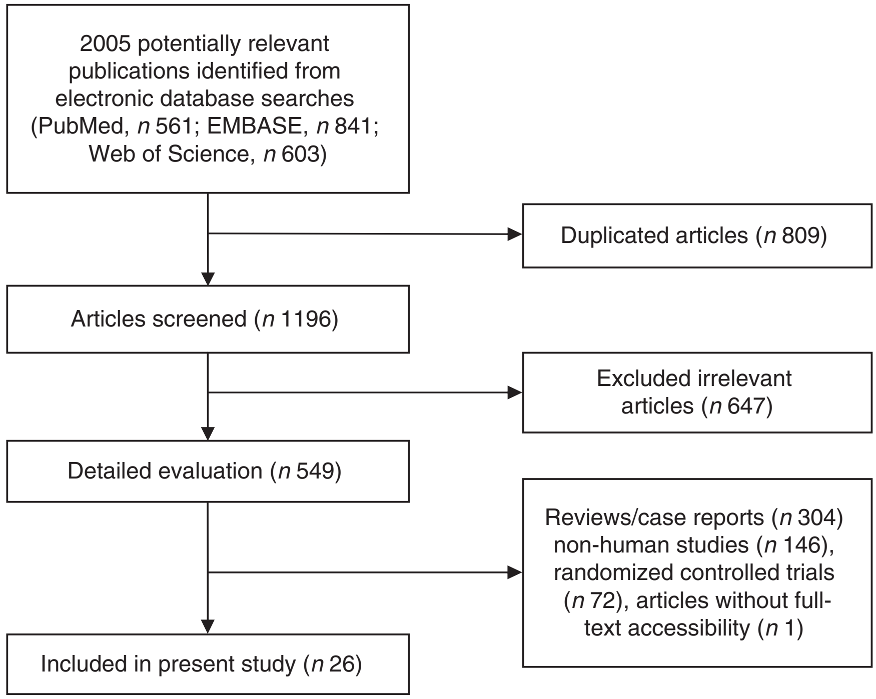

Fig. 1 Flowchart for the identification of studies included in the present meta-analysis on associations of vegetable and/or fruit consumption with metabolic syndrome

five cohort studies. Four of the included studies were performed in European countries (Finland[25,37], Poland[26] and Portugal[21]), fourteen studies were conducted in Asian countries (Korea[16,17,20,24,27,30,38], India[22], Taiwan[32,40], Iran[34,39], Japan[33] and China[29]), four studies were conducted in the USA[7,19,28,31] and the other four studies were from Chile[35], Suriname[18] and Brazil[23,36]. Twenty-three articles included both male and female participants[7,17–26,28–33,35–40], with three articles including only female or male participants[16,27,34]. The sample size ranged from 305 to 27 656 for a total number of 115 727. The criteria for MetS were those of the National Cholesterol Education Program Adult Treatment Panel III in eighteen articles[16–18,21–25,27,28,30,32,34–36,38–40], the International Diabetes Federation in three[19,20,33] and the American Heart Association in two studies[7,26]. Moreover, the criteria proposed by Alberti *et al.* were used in two studies[29,37]. Finally, sixteen[16,17,20,21,23–25,27,30,32,34,35,37–40], sixteen[16,17,20–24,27–30,33,34,35,37,39] and eight articles[7,16,18,19,26,31,36,39] were related to the associations of vegetable, fruit, and vegetable and fruit consumption with MetS, respectively.

Association between vegetable consumption and metabolic syndrome

The overall multivariable-adjusted RR evidenced a negative association between vegetable consumption and MetS (RR = 0·89, 95 % CI 0·85, 0·93; $P < 0{\cdot}001$; Fig. 2). No substantial level of heterogeneity was observed among studies ($P = 0{\cdot}123$, $I^2 = 30{\cdot}1\,\%$). No evidence of publication bias was observed among the included studies according to the Begg rank-correlation test ($P = 0{\cdot}964$). The results of subgroup analysis for vegetable consumption are shown in Table 2. No significant relationship between green vegetable consumption and MetS was found according to the overall multivariable-adjusted RR (RR = 1·10, 95 % CI 0·98, 1·24; $P = 0{\cdot}12$). No substantial level of heterogeneity was observed among studies ($P = 0{\cdot}47$, $I^2 = 0\,\%$). No evidence of publication bias was observed among the included studies according to the Begg rank-correlation test ($P = 1{\cdot}000$).

Association between fruit consumption and metabolic syndrome

The overall multivariable-adjusted RR showed that fruit consumption was negatively associated with MetS (RR = 0·81, 95 % CI 0·75, 0·88; $P < 0{\cdot}001$; Fig. 3). A substantial level of heterogeneity was observed among studies ($P = 0{\cdot}001$, $I^2 = 61{\cdot}6\,\%$). No evidence of publication bias was observed among the included studies according to the Begg rank-correlation test ($P = 0{\cdot}079$). The results of subgroup analysis for fruit consumption are shown in Table 3.

Association of vegetable and fruit consumption with metabolic syndrome

The overall multivariable-adjusted RR showed that vegetable and fruit consumption was negatively associated with MetS (RR = 0·75, 95 % CI 0·63, 0·90; $P = 0{\cdot}002$; Fig. 4).

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Table 1 Characteristics of the individual studies included in the present meta-analysis on associations of vegetable and/or fruit consumption with metabolic syndrome (MetS)

Study	Location	Age (years)	Male (%)	Sample size	Study design	Adjustments	Exposure	Exposure assessment	Diagnostic criteria of MetS	NOS score
Esmaillzadeh *et al.* (2006)[34]	Iran	40–60	NA	486	Cross-sectional	Age, BMI, energy intake, cholesterol intake, percentage of energy from fat, cigarette smoking, physical activity level, current oestrogen use, menopausal status, family history of diabetes or stroke, intakes of whole grains, refined grains, dairy products, meat and fish, mutual effects of fruit and vegetable intakes, C-reactive protein	Vegetable Fruit	FFQ	NCEP ATP III	6
Pan and Pratt (2008)[28]	USA	12–19	50·8	4450	Cross-sectional	Age, BMI, sex, ethnicity, poverty status, physical activity level	Fruit	24 h dietary recall	NCEP ATP III	6
Lutsey *et al.* (2008)[7]	USA	45–64	44·1	9514	Cohort	Age, sex, race, education, centre, total energy intake, smoking status, pack-years, physical activity level, intakes of meat, dairy, whole grains and refined grains	Vegetable and fruit	FFQ	AHA	8
Kelishadi *et al.* (2008)[39]	Iran	6–18	46·7	4811	Cross-sectional	Age	Vegetable Fruit Vegetable and fruit	FFQ	NCEP ATP III	6
Kwaśniewska *et al.* (2009)[26]	Poland	20–74	47·4	1187	Cross-sectional	BMI, smoking, physical activity	Vegetable and fruit	FFQ	AHA	6
Shin *et al.* (2009)[27]	Korea	>30	100	7081	Cross-sectional	Age, family history of type 2 diabetes, smoking status, physical activity	Vegetable Fruit	FFQ	NCEP ATP III	6
Kouki *et al.* (2001)[25]	Finland	57–78	49·7	1334	Cross-sectional	Age, smoking, alcohol consumption, education	Vegetable	4 d food record	NCEP ATP III	6
Jung *et al.* (2011)[24]	Korea	30–59	43	596	Case–control	Age, sex, energy intake	Vegetable Fruit	3 d food record	NCEP ATP III	8
Cho *et al.* (2012)[38]	Korea	>30	42·9	1388	Cross-sectional	Age	Vegetable	FFQ	NCEP ATP III	6
Jaaskelainen *et al.* (2012)[37]	Finland	3–18	45·6	2128	Cohort	Age, sex	Vegetable Fruit	FFQ	Criteria proposed by Alberti *et al.*	8
de Oliveira *et al.* (2012)[23]	Brazil	>35	73·4	305	Cross-sectional	Age, sex, total energy intake, BMI	Vegetable Fruit	24 h dietary recall	NCEP ATP III	6
Prasad *et al.* (2012)[22]	India	20–80	50·1	1178	Cross-sectional	Not mentioned	Fruit	FFQ	NCEP ATP III	6
Castanho *et al.* (2013)[21]	Portugal	15–88	25	636	Cross-sectional	Sex, total energy intake	Vegetable Fruit	24 h dietary recall	NCEP ATP III	5
Baik *et al.* (2013)[20]	Korea	40–69	NA	5251	Cohort	Age, sex, income, occupation, education, smoking status, alcohol intake, quartiles of MET-h/d, study site, *FTO* genotypes, quartiles of energy intake, quintiles of food groups or food items that are presented in their table	Vegetable Fruit	FFQ	IDF	7
Masaki (2013)[33]	Japan	20–69	NA	534	Cross-sectional	Age, physical activity level, smoking and drinking status, other confounding variables	Fruit	NA	IDF	6
Boucher *et al.* (2013)[31]	USA	NA	NA	1059	Cohort	Age, education, gender, diabetes, heart disease status	Vegetable and fruit	NA	NA	7

Table 1 *Continued*

Study	Location	Age (years)	Male (%)	Sample size	Study design	Adjustments	Exposure	Exposure assessment	Diagnostic criteria of MetS	NOS score
Lin *et al.* (2013)(32)	Taiwan	>65	67·8	888	Cohort	Age, gender, blood pressure, serum creatinine, ALT, uric acid, urine protein, initial MetS score, smoking, alcohol drinking, exercise, teeth brushing, milk intake	Vegetable	FFQ	NCEP ATP III	8
Chen *et al.* (2014)(41)	Taiwan	>15	48	6591	Cross-sectional	Age, sex	Vegetable	FFQ	NCEP ATP III	6
Neia Martini *et al.* (2014)(36)	Brazil	>20	NA	1112	Cross-sectional	NA	Vegetable and fruit	NA	NCEP ATP III	6
Park *et al.* (2015)(30)	Korea	>20	40·8	27 656	Cross-sectional	Age, BMI, residence area, education level, smoking, drinking status, menopausal status, exercise, walking, serum AST and ALT	Vegetable Fruit	FFQ	NCEP ATP III	6
Dussaillant *et al.* (2015)(35)	Chile	>18	48	2561	Cross-sectional	Sex, BMI, age, education level, activity level	Vegetable Fruit	FFQ	NCEP ATP III	6
Krishnadath *et al.* (2016)(18)	Suriname	39·2	48·5	2646	Cross-sectional	Age, sex	Vegetable and fruit	FFQ	NCEP ATP III	6
Fletcher *et al.* (2016)(19)	USA	12–19	53·1	1379	Cross-sectional	Age, sex, ethnicity, socio-economic position, self-reported physical activity level, dietary intake under-reporting, television viewing time	Vegetable and fruit	24 h dietary recall	IDF	6
Wu *et al.* (2016)(29)	China	18–79	46·2	16 831	Cross-sectional	Sex, age, location distribution	Fruit	FFQ	Criteria proposed by Alberti *et al.*	6
Hong and Kim (2017)(16)	Korea	40–64	0	2999	Cross-sectional	Age, education level, household income, living with spouse, current smoker, current alcohol drinker, multivitamin use, menopausal status, energy intake, energy-adjusted carbohydrate intake, energy-adjusted Na intake	Vegetable Fruit Vegetable and fruit	24 h dietary recall	NCEP ATP III	6
Kim and Choi (2016)(11)	Korea	30–64	39·8	11 029	Cross-sectional	Age, sex, total energy intake, diet modification, education level	Vegetable Fruit	FFQ	NCEP ATP III	6

NOS, Newcastle–Ottawa scale; NA, not applicable; MET, metabolic equivalent of task; ALT, alanine aminotransferase; AST, aspartate aminotransferase; NCEP ATP III, National Cholesterol Education Program–Adult Treatment Panel III; AHA, American Heart Association; IDF, International Diabetes Federation.

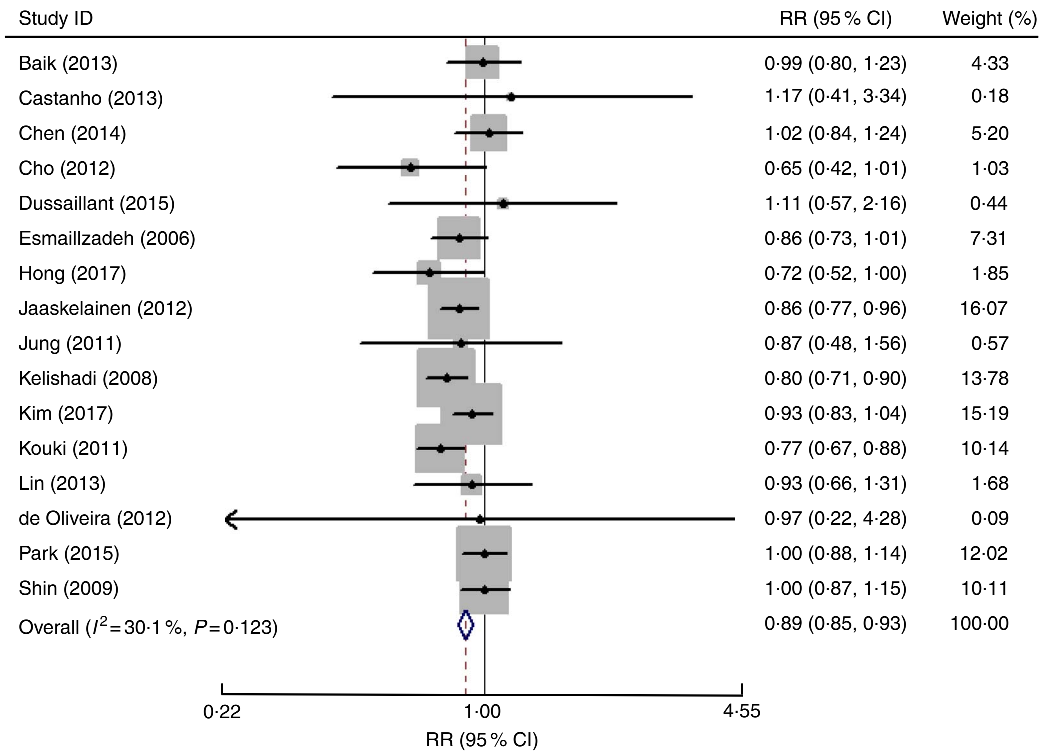

Fig. 2 Forest plot of the overall multivariable-adjusted relative risk (RR) of metabolic syndrome for the highest *v.* the lowest category of vegetable consumption. The study-specific RR and 95 % CI are represented by the black diamond and the horizontal line, respectively; the area of the grey square is proportional to the specific-study weight to the overall meta-analysis. The centre of the open diamond and the vertical dashed line represent the pooled RR and the width of the open diamond represents the pooled 95 % CI

Table 2 Subgroup analyses of vegetable consumption and metabolic syndrome (MetS)

Stratification	No. of studies	Pooled RR	95 % CI	Heterogeneity
All studies	16	0·89	0·85, 0·93	$P=0{\cdot}12$; $I^2=30{\cdot}1\,\%$
Type of vegetable				
Green vegetables	3	1·10	0·98, 1·24	$P=0{\cdot}47$; $I^2=0\,\%$
Gender				
Male	6	0·91	0·81, 1·03	$P=0{\cdot}005$; $I^2=70\,\%$
Female	8	0·89	0·83, 0·95	$P=0{\cdot}12$; $I^2=39\,\%$
Design				
Cross-sectional or case–control	13	0·89	0·85, 0·94	$P=0{\cdot}07$; $I^2=40\,\%$
Cohort	3	0·89	0·81, 0·98	$P=0{\cdot}50$; $I^2=0\,\%$
Diagnostic criteria of MetS				
NCEP ATP III	14	0·89	0·85, 0·94	$P=0{\cdot}09$; $I^2=35\,\%$
IDF	1	0·99	0·80, 1·23	–
Other	1	0·86	0·77, 0·96	–
Geographical region				
Asia	11	0·92	0·87, 0·96	$P=0{\cdot}13$; $I^2=34\,\%$
Europe	3	0·83	0·76, 0·90	$P=0{\cdot}38$; $I^2=0\,\%$
South America	2	1·09	0·59, 1·99	$P=0{\cdot}87$; $I^2=0\,\%$
Sample size				
<1000	5	0·88	0·76, 1·01	$P=0{\cdot}98$; $I^2=0\,\%$
>1000	11	0·89	0·83, 0·96	$P=0{\cdot}02$; $I^2=52\,\%$
Age of population				
Adult	14	0·92	0·87, 0·97	$P=0{\cdot}21$; $I^2=22\,\%$
Adolescents	2	0·83	0·77, 0·90	$P=0{\cdot}38$; $I^2=0\,\%$

RR, relative risk; NCEP ATP III, National Cholesterol Education Program–Adult Treatment Panel III; IDF, International Diabetes Federation.

A substantial level of heterogeneity was observed among studies ($P<0{\cdot}001$, $I^2=92{\cdot}3\,\%$). No evidence of publication bias was observed among the included studies according to the Begg rank-correlation test ($P=0{\cdot}127$). The results of subgroup analysis for vegetable and fruit consumption are shown in Table 4.

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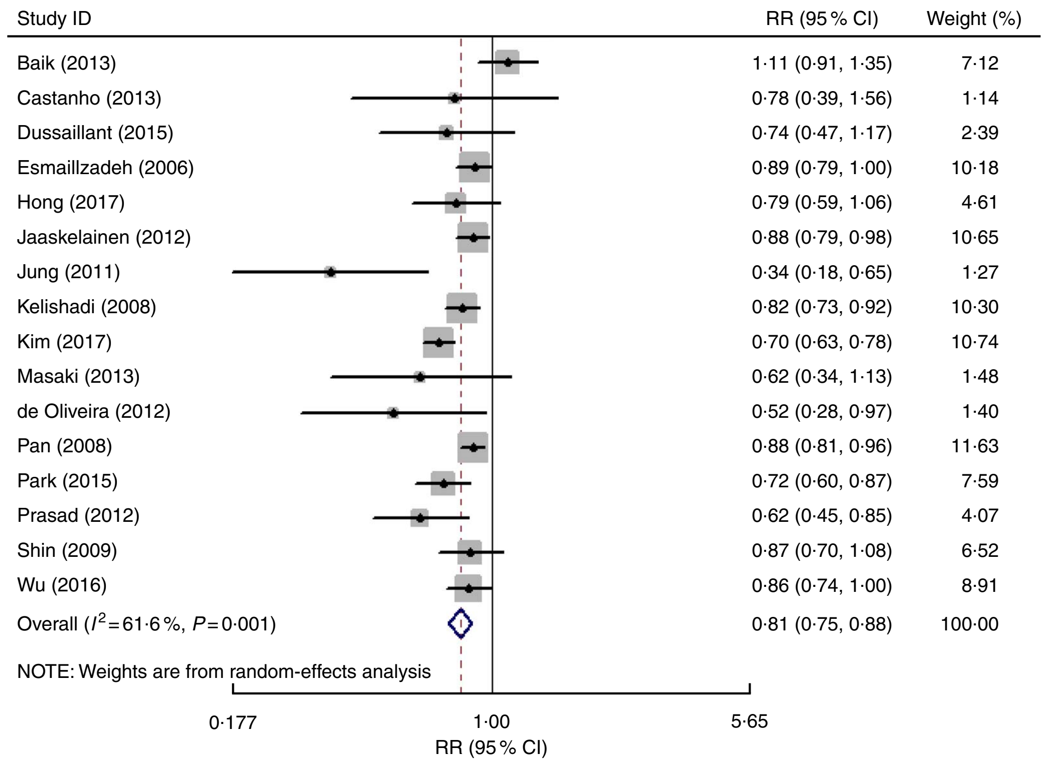

Fig. 3 Forest plot of the overall multivariable-adjusted relative risk (RR) of metabolic syndrome for the highest *v.* the lowest category of fruit consumption. The study-specific RR and 95 % CI are represented by the black diamond and the horizontal line, respectively; the area of the grey square is proportional to the specific-study weight to the overall meta-analysis. The centre of the open diamond and the vertical dashed line represent the pooled RR and the width of the open diamond represents the pooled 95 % CI

Table 3 Subgroup analyses of fruit consumption and metabolic syndrome (MetS)

Stratification	No. of studies	Pooled RR	95 % CI	Heterogeneity
All studies	16	0·81	0·75, 0·88	$P = 0·12$; $I^2 = 61·6$ %
Gender				
Male	4	0·83	0·76, 0·90	$P = 0·91$; $I^2 = 0$ %
Female	6	0·80	0·70, 0·91	$P = 0·02$; $I^2 = 63$ %
Design				
Cross-sectional or case–control	14	0·78	0·72, 0·85	$P = 0·008$; $I^2 = 54$ %
Cohort	2	0·97	0·78, 1·22	$P = 0·04$; $I^2 = 75$ %
Diagnostic criteria of MetS				
NCEP ATP III	12	0·78	0·71, 0·85	$P = 0·004$; $I^2 = 59$ %
IDF	2	0·89	0·51, 1·55	$P = 0·07$; $I^2 = 69$ %
Other	2	0·87	0·80, 0·95	$P = 0·81$; $I^2 = 0$ %
Geographical region				
Asia	11	0·92	0·87, 0·96	$P = 0·13$; $I^2 = 34$ %
Europe	2	0·88	0·79, 0·98	$P = 0·74$; $I^2 = 0$ %
North and South America	3	0·87	0·80, 0·94	$P = 0·20$; $I^2 = 38$ %
Sample size				
<1000	5	0·63	0·44, 0·92	$P = 0·02$; $I^2 = 66$ %
>1000	11	0·82	0·76, 0·89	$P = 0·002$; $I^2 = 64$ %
Age of population				
Adult	13	0·78	0·69, 0·87	$P = 0·001$; $I^2 = 65$ %
Adolescents	3	0·87	0·82, 0·92	$P = 0·38$; $I^2 = 0$ %

RR, relative risk; NCEP ATP III, National Cholesterol Education Program–Adult Treatment Panel III; IDF, International Diabetes Federation.

Sensitivity analysis

The results of the sensitivity analysis showed only minimal changes in magnitude of the pooled RR and heterogeneity when any one study was excluded from the meta-analysis, indicating that no individual study had excessive influence on these robust aggregated results (data not shown).

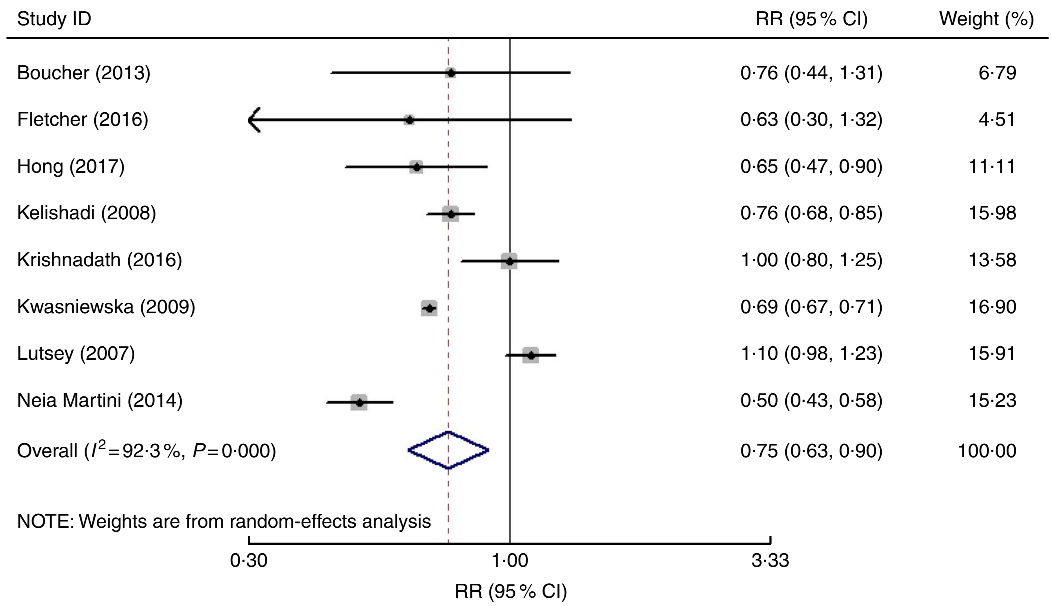

Fig. 4 Forest plot of the overall multivariable-adjusted relative risk (RR) of metabolic syndrome for the highest *v.* the lowest category of vegetable and fruit consumption. The study-specific RR and 95 % CI are represented by the black diamond and the horizontal line, respectively; the area of the grey square is proportional to the specific-study weight to the overall meta-analysis. The centre of the open diamond and the vertical dashed line represent the pooled RR and the width of the open diamond represents the pooled 95 % CI

Table 4 Subgroup analyses of vegetable and fruit consumption and metabolic syndrome (MetS)

Stratification	No. of studies	Pooled RR	95 % CI	Heterogeneity
All studies	8	0·75	0·63, 0·90	$P<0·001$; $I^2=92·3\,\%$
Gender				
Male	3	0·67	0·56, 0·80	$P=0·007$; $I^2=69\,\%$
Female	4	0·66	0·58, 0·76	$P=0·10$; $I^2=52\,\%$
Design				
Cross-sectional or case–control	6	0·69	0·60, 0·81	$P<0·001$; $I^2=84\,\%$
Cohort	2	1·08	0·97, 1·21	$P=0·19$; $I^2=41\,\%$
Diagnostic criteria of MetS				
NCEP ATP III	4	0·70	0·53, 0·94	$P<0·001$; $I^2=90\,\%$
IDF	1	0·63	0·30, 1·32	–
AHA	2	0·87	0·55, 1·37	$P<0·001$; $I^2=98\,\%$
Geographical region				
Asia	2	0·75	0·67, 0·83	$P=0·37$; $I^2=0\,\%$
Europe	1	0·69	0·67, 0·71	–
USA	3	1·07	0·96, 1·20	$P=0·16$; $I^2=46\,\%$
South America	2	0·70	0·36, 1·39	$P<0·001$; $I^2=96\,\%$
Sample size				
<1000	0	–	–	–
>1000	8	0·75	0·63, 0·90	$P<0·001$; $I^2=92\,\%$
Age of population				
Adult	5	0·76	0·58, 0·99	$P<0·001$; $I^2=95\,\%$
Adolescents	2	0·76	0·68, 0·84	$P=0·62$; $I^2=0\,\%$

RR, relative risk; NCEP ATP III, National Cholesterol Education Program–Adult Treatment Panel III; IDF, International Diabetes Federation; AHA, American Heart Association.

Meta-regression

Low ($P=0·123$; $I^2=30·1\,\%$), moderate ($P<0·001$; $I^2=61·6\,\%$) and high ($P<0·001$; $I^2=92\,\%$) heterogeneity was demonstrated for the associations of vegetable, fruit, and vegetable and fruit consumption with MetS, respectively. To explore the sources of heterogeneity, univariate meta-regression with covariates was performed. For vegetable consumption, the results showed the following: publication year ($P=0·289$), sample size ($P=0·045$), gender ($P=0·515$), age of the population ($P=0·195$), geographical region ($P=0·316$), study design ($P=0·809$), diagnostic criteria of MetS ($P=0·872$). Only sample size ($P=0·045$) seemed to contribute to the heterogeneity in this analysis. With regard to fruit consumption, the results showed the following:

publication year ($P=0{\cdot}269$), sample size ($P=0{\cdot}581$), gender ($P=0{\cdot}695$), age of the population ($P=0{\cdot}377$), geographical region ($P=0{\cdot}871$), study design ($P=0{\cdot}068$), diagnostic criteria of MetS ($P=0{\cdot}192$). None of these covariates was found to contribute to the moderate heterogeneity. In addition, concerning fruit and vegetable consumption, the results showed the following: publication year ($P=0{\cdot}419$), sample size ($P=0{\cdot}05$), gender ($P=0{\cdot}046$), age of the population ($P=0{\cdot}870$), geographical region ($P=0{\cdot}857$), study design ($P=0{\cdot}152$), diagnostic criteria of MetS ($P=0{\cdot}698$). Gender ($P=0{\cdot}046$) and sample size ($P=0{\cdot}05$) seemed to contribute to the high heterogeneity in this analysis.

Discussion

In the present meta-analysis, a total of twenty-six observational studies were included for examination. The pooled analysis showed that vegetable and/or fruit consumption were negatively associated with MetS. However, the consumption of green vegetables might not be associated with MetS.

The underlying mechanism behind the negative associations of vegetable and/or fruit consumption with MetS may be explained as follows. First, as an established biomarker for vegetable and fruit consumption, vitamin C was found to be associated with a lower risk of MetS[11]. Second, fibre, another important substance in vegetables and fruits, was proved to be inversely associated with MetS[12–14]. Third, the fat content in vegetables was also reported to be associated with a lower risk of MetS[45]. Finally, as fruits and vegetables are good sources of antioxidants and anti-inflammatory agents, their intake may be beneficial for MetS patients[15,46]. On the other hand, the Mediterranean diet and the Dietary Approaches to Stop Hypertension (DASH) diet, which are rich in vegetable and fruit consumption, were reported to be negatively associated with either risk or prevalence of MetS[47–52]. These findings are strongly consistent with the results of the present study. Therefore, it is speculated that vegetable and fruit consumption may exert a positive effect on MetS.

Recently, an earlier meta-analysis including eight randomized controlled trials explored the influence of fruits and vegetables on MetS[46]. Interestingly, it reported that fruit and vegetable intake was associated only with a reduction in diastolic blood pressure, but not in waist circumference, systolic blood pressure, fasting glucose, HDL cholesterol and TAG levels in MetS patients. However, that meta-analysis only investigated the effect of fruit and vegetable interventions on the components of MetS, with no trial reporting changes in the prevalence of MetS. Therefore, further randomized controlled trials that aim at MetS directly are still needed.

Generally, radish leaf, spinach, cucumber and pepper are regarded as 'green vegetables', and cabbage, radish, sprout, carrot, pumpkin and tomato are regarded as 'white vegetables'[30]. Luo *et al*. found that the consumption of white vegetables was inversely associated with the risk of colorectal cancer, while green vegetable intake was not[53]. Therefore, it is speculated that the biological effect of vegetables may vary with variety. This was also the subject that the present study intended to address. However, due to the limited number of included studies (only three), subgroup analysis was only conducted for green vegetables in the present meta-analysis. Surprisingly, the results showed that green vegetable consumption was not associated with MetS. With respect to this obvious difference between the results for vegetables as a whole and for green vegetables, several speculations were raised as follows. First of all, the reliability of the results might be weakened since only three studies related to green vegetables were included for subgroup analysis. Second, white vegetables might have a significant contribution to the anti-MetS effect of vegetables as a whole. Furthermore, the components in green vegetables are complicated, and some neglected substances might work against the effect of vitamin C or fibre. Although some inconsistency in results with regard to gender, study design, diagnostic criteria of MetS and geographical region was found in subgroup analysis (Tables 2–4), it might be due to the high heterogeneity or limited number of included studies. As a consequence, more well-designed studies with detailed specification of vegetable varieties are needed.

The strengths of the present meta-analysis are mainly reflected in the following aspects. First, it is the first meta-analysis of observational studies aiming at the associations of vegetable and/or fruit consumption with MetS based on the most comprehensive literature search to date. Second, the included studies were analysed based on adjusted results and large samples. Third, the present study can serve as a reference and indication for further research (specify the variety of vegetable). Limitations of the present study should also be acknowledged. First, the substantial level of heterogeneity might have distorted the results. Second, due to the limitation of relevant literature, only a limited number of observational studies qualified for the current meta-analysis. Third, the classification of exposure may also vary greatly among individuals. Fourth, the diagnostic criteria of MetS and the selection of adjusted factors were not uniform. Fifth, since only a few studies specified the varieties of vegetable, some issues could not be addressed. Finally, due to the limitation of insufficient data at present, a dose–response analysis could not be performed in the current meta-analysis. These limitations might weaken the significance of the present study.

Conclusions

The existing evidence suggests that vegetable and/or fruit consumption are negatively associated with MetS. However, due to the limited number of included studies, the consumption of green vegetables might not be associated with MetS. More well-designed prospective cohort studies that specify vegetable varieties are needed to elaborate the concerned issues further.

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