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The association between milk consumption and the metabolic syndrome: a cross-sectional study of the residents of Suzhou, China and a meta-analysis

Khemayanto Hidayat[1], Lu-Gang Yu[2], Jin-Rong Yang[1], Xue-Ying Zhang[3], Hui Zhou[2], Yu-Jie Shi[4], Biao Liu[4]* and Li-Qiang Qin[1]*

[1]*Department of Nutrition and Food Hygiene, School of Public Health, Soochow University, Suzhou 215123, People's Republic of China*
[2]*Suzhou Industrial Park Centers for Disease Control and Prevention, Suzhou 215021, People's Republic of China*
[3]*Suzhou Vocational Health College, Suzhou 215009, People's Republic of China*
[4]*Jinshan Branch Company, Inner Mongolia Yili Industrial Group Co., Ltd., Hohhot 010110, People's Republic of China*

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Abstract

The association between milk consumption and the metabolic syndrome remains inconclusive, and data from Chinese populations are scarce. We conducted a cross-sectional study to investigate the association between milk consumption and the metabolic syndrome and its components among the residents of Suzhou Industrial Park, Suzhou, China. A total of 5149 participants were included in the final analysis. A logistic regression model was applied to estimate the OR and 95 % CI for the prevalence of the metabolic syndrome and its components according to milk consumption. In addition, the results of our study were further meta-analysed with other published observational studies to quantify the association between the highest *v.* lowest categories of milk consumption and the metabolic syndrome and its components. There was no significant difference in the odds of having the metabolic syndrome between milk consumers and non-milk consumers (OR 0·86, 95 % CI 0·73, 1·01). However, milk consumers had lower odds of having elevated waist circumference (OR 0·78, 95 % CI 0·67, 0·92), elevated TAG (OR 0·83, 95 % CI 0·70, 0·99) and elevated blood pressure (OR 0·85, 95 % CI 0·73, 0·99). When the results were pooled together with other published studies, higher milk consumption was inversely associated with the risk of the metabolic syndrome (relative risk 0·80, 95 % CI 0·72, 0·88) and its components (except elevated fasting blood glucose); however, these results should be treated with caution as high heterogeneity was observed. In summary, the currently available evidence from observational studies suggests that higher milk consumption may be inversely associated with the metabolic syndrome.

Key words: Metabolic syndrome: Milk: Waist circumference: Lipids: Blood pressure

The metabolic syndrome is a cluster of cardiometabolic risk factors that may increase the risk of developing type 2 diabetes mellitus and CVD. These cardiometabolic risk factors include elevated blood glucose, elevated blood pressure, dyslipidaemia and abdominal obesity. Maintaining a healthy diet is essential for the prevention of the metabolic syndrome[1]. There is emerging evidence that certain nutrients in dairy products (e.g. protein, Ca, Mg, K and vitamin D) may have a beneficial effect on metabolic syndrome components[2–5]. The evidence of the association between dairy product consumption and the metabolic syndrome remains inconclusive. Although observational studies generally demonstrate an inverse association between dairy product consumption and the metabolic syndrome[6,7], many aspects of the association between dairy product consumption and the metabolic syndrome remain unclear. In this case, the potential effect modifiers (e.g. dairy product type, fat content and subpopulation) for this association have not been well elucidated. Evidence on the association between dairy consumption and the metabolic syndrome is predominantly derived from studies conducted in Western countries[8–18], with only a few studies from Asian countries[19–24]. Given that Asian populations differ from Western populations with respect to dietary pattern, cultural characteristics or amounts and types of dairy products consumed[25,26], better understanding of the association between consumption of dairy product and the metabolic syndrome in Asian populations may provide valuable information that could be useful to refine the evidence on this topic. Thus far, a number of studies have investigated the association between milk consumption and the metabolic syndrome in Western[15–18,27] and Asian[21–24,28–30] populations. However,

Abbreviations: JIS, joint interim statement; RR, relative risk.

* **Corresponding authors:** Li-Qiang Qin, fax +86 512 6588 0071, email qinliqiang@suda.educn; Biao Liu, fax +86 471357947, email bliu@yili.com

these studies have yielded inconsistent results, possibly due to the heterogeneity in study design, milk consumption levels and metabolic syndrome definition. Nearly all Asian studies investigating the association between milk consumption and the metabolic syndrome were conducted in Korean populations. To the best of our knowledge, only two studies[29,30] have investigated this association in Chinese populations; however, both studies did not investigate the extent to which milk consumption may influence the metabolic syndrome components. Milk consumption may influence the metabolic syndrome components to different extents[18,21–23]. We conducted a cross-sectional study to investigate the association between milk consumption and the metabolic syndrome and its components among the residents of Suzhou Industrial Park, which represent Southeast Chinese populations. In addition, we also performed a meta-analysis of observational studies to quantify the association between milk consumption and the metabolic syndrome and its components.

Methods

Study population

A total of 7998 residents of Suzhou Industrial Park (Suzhou City, Jiangsu Province) aged 18 years and older were randomly recruited via hospitals and health examination centres throughout Suzhou Industrial Park between July 2013 and November 2014. Of these 7998 participants, 614 participants with missing information on milk consumption and 2235 participants with missing information on any of the metabolic syndrome components were excluded. Finally, a total of 5149 participants remained for the present analysis. The research protocol was approved by the Ethics Committee of Soochow University. Written informed consent was obtained from all participants.

Blood samples and measurements

The overnight 10–12-h fasting blood samples were drawn by venepuncture to measure serum glucose, total cholesterol, TAG, HDL-cholesterol and LDL-cholesterol. The concentrations of glucose, total cholesterol, TAG, HDL-cholesterol and LDL-cholesterol in plasma were measured enzymatically using an autoanalyzer (Olympus AU640). Systolic and diastolic blood pressure levels were measured in a seated position three times consecutively at 1-min intervals using a manual mercury sphygmomanometer. Body weight, height and waist circumference were measured by trained personnel according to a standard protocol. Measurements of height and waist circumference were taken to the nearest 0·1 cm, while weight was measured to the nearest 0·1 kg. Waist circumference was measured at the narrowest point between the lower costal border and the top of the iliac crest. BMI was calculated as weight in kg divided by height in m^2.

Dietary intake assessment

An interviewer-administered FFQ was used to collect information about dietary intake. Briefly, the participants were asked about the frequency and portion size of each major food group (red meat, poultry, fish, fruit, vegetables, soya, nut, salted vegetables and milk) consumed in the previous year. The frequency of food group intake was recorded as never, less than once/month, 1–3 times/month, 1–2 times/week, 3–4 times/week, 5–6 times/week, 1 time/d and 1 time/d. The portion size was estimated using traditional weight units (i.e. 1 jin = 0·5 kg; 1 liang = 0·5 g). The retrieved records were then converted into mean daily consumption (g/d) by multiplying the standard portion size (g) by the consumption frequency for each food and making the appropriate division for the period assessed to obtain daily consumption. Although the information regarding the food groups mentioned above was collected, the information on other important dietary factors, including total energy intake and dietary nutrient intake (e.g. carbohydrate, protein, fat, cholesterol, vitamin, mineral and fibre), was not collected because the survey was not specifically established for nutritional studies.

Other covariates

All participants were interviewed by trained interviewers using a standardised questionnaire to collect the information about age, sex, education level, physical activity, alcohol intake, smoking status, sleep duration, television watching duration and the use of medications for diabetes, dyslipidaemia or hypertension. Education level was classified into lower than high school, high school or vocational school, and college or above. Smoking status was categorised into never, former and current smokers. Alcohol intake was classified into three groups: 0/week, 1–3/week and >3/week.

Metabolic syndrome definition

The metabolic syndrome was defined according to the joint interim statement (JIS) issued by several internationally renowned institutions[31]. According to the JIS criteria, participants were judged as having the metabolic syndrome if they had three or more of the following components:

1. Elevated waist circumference for Asian populations (≥90 cm in men and ≥80 cm in women).
2. Elevated TAG (≥150 mg/dl (1·7 mmol/l) or drug treatment for elevated TAG).
3. Reduced HDL-cholesterol (<40 mg/dl (1·04 mmol/l) in men and <50 mg/dl (1·3 mmol/l) in women or drug treatment for reduced HDL-cholesterol).
4. Elevated blood pressure (≥130 mmHg systolic or ≥85 mmHg diastolic or drug treatment for elevated blood pressure).
5. Elevated fasting blood glucose (≥100 mg/dl (5·6 mmol/l) or drug treatment for elevated blood glucose).

Data analysis

The mean daily intake of milk in this population was very low (approximately 20 g/d), as more than 80 % (n 4244) of the study participants did not consume milk. Therefore, we preferred not to report the results according to different categories of milk intake. As a solution to this issue, we compared milk consumers and non-milk consumers (reference group). Participants who reported consuming any amount of milk were considered as ‘milk consumers’, whereas participants who reported zero

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quantity of milk were classified as 'non-milk consumers'. The χ^2 test (for categorical variables) and multiple linear regressions (for continuous variables) were used to analyse the difference in characteristics between milk consumers and non-milk consumers. Continuous variables and categorical variables were reported as means and standard deviations and as numbers and percentages, respectively. A logistic regression model was applied to estimate the OR and 95 % CI for the prevalence of the metabolic syndrome and its components. The multivariable models were adjusted for age, sex, education, smoking, alcohol, physical activity, sleep duration, television watching duration, BMI and consumption of red meat, poultry, fish, fruit, vegetable, nut, soya and salted vegetable. All statistical analyses were performed using SPSS version 20.0 (SPSS Inc.). All P values were two-sided, and the level of significance was set at <0·05.

Meta-analysis

We conducted a meta-analysis that included data from the present study and published observational studies that reported the risk estimates (OR or hazard ratios) for the association between milk consumption and the metabolic syndrome in adults. The studies were identified through a PubMed database search from inception to July 2019, with no restrictions. The following search terms were used to identify the relevant studies: (milk OR dairy) AND (metabolic syndrome OR insulin resistance syndrome). From each study, we extracted the most fully adjusted risk estimates. For statistical purposes, the hazard ratios from cohort studies and the OR from cross-sectional studies were deemed equivalent to the relative risks (RR). Study-specific results were pooled under a random-effects model[32] to estimate the summary RR with corresponding CI for the association between the highest *v.* lowest categories of milk consumption and the metabolic syndrome and its components. For the metabolic syndrome, we also performed stratified and meta-regression analyses according to study design (prospective cohort and cross-sectional), study populations (Asian and Western), the metabolic syndrome criteria (JIS and National Cholesterol Education Program Adult Treatment Panel III) and adjustment for certain confounders to investigate the source of heterogeneity and potential effect modifiers. The statistical heterogeneity across studies was assessed by the I^2 statistic for which the degree of heterogeneity was classified into the following cut-off points: <25 % (low heterogeneity), 25–50 % (moderate heterogeneity) and >50 (high heterogeneity)[33]. The potential publication bias was evaluated by Begg's rank correlation test and Egger's linear regression test[34]. If publication bias was detected, the trim and fill method was performed to adjust the bias[35]. All statistical analyses were performed using STATA software, version 11.0 (StataCorp.).

Results

The present study

The selected participant characteristics according to milk consumption are summarised in Table 1. Compared with non-milk consumers, milk consumers were younger, more educated, more active physically, less likely to be current smokers, drank less alcohol and spent more time watching television. Milk consumers had a lower body weight, BMI, waist circumference, LDL-cholesterol, systolic blood pressure and diastolic blood pressure but had a higher HDL-cholesterol. Furthermore, milk consumers had a lower consumption of poultry, red meat, fish and soya but had a higher consumption of fruit and nut. In general, milk consumers appeared to have a healthier lifestyle, healthier eating habits and more favourable cardiometabolic risk factors than non-milk consumers.

The prevalence of the metabolic syndrome was 40·8 % among milk consumers and 47·5 % among non-milk consumers. The OR for the prevalence of the metabolic syndrome and its components according to milk consumption are presented in Table 2. In the unadjusted model, the odds of having the metabolic syndrome were 24 % (OR 0·76, 95 % CI 0·66, 0·88) lower for milk consumers compared with non-milk consumers; however, the observed inverse association was attenuated to become statistically non-significant (OR 0·86, 95 % CI 0·73, 1·01) in the multivariable model. Regarding the metabolic syndrome components, milk consumers had lower odds of having elevated waist circumference (OR 0·78, 95 % CI 0·67, 0·92), elevated TAG (OR 0·83, 95 % CI 0·70, 0·99) and elevated blood pressure (OR 0·85, 95 % CI 0·73, 0·99) after adjustment for potential confounders; no association was observed for reduced HDL-cholesterol (OR 1·14, 95 % CI 0·96, 1·36) and elevated fasting blood glucose (OR 0·99, 95 % CI 0·82, 1·20).

Meta-analysis of the present study and published observational studies

The flow chart of the study selection process with the reasons for exclusion is presented in online Supplementary Fig. S1. We identified eleven studies that were eligible for inclusion in the present meta-analysis. The characteristics of the included studies are summarised in online Supplementary Table S1. In the main meta-analysis of the present study and eleven other studies[15–18,21–24,27–29], the pooled RR of the metabolic syndrome for the highest *v.* lowest categories of milk consumption was 0·80 (95 % CI 0·72, 0·88; Fig. 1), with high heterogeneity (I^2 73·5 %). In general, a consistent tendency towards an inverse association was observed across subgroups, although some did not reach statistical significance (Table 3). Meta-regression analyses revealed that the overall findings were not significantly different by study design, study populations, metabolic syndrome criteria and adjustment for certain confounders (all $P_{\text{meta-regression}} \geq 0·26$). Although study design did not appear to modify the overall association ($P_{\text{meta-regression}} = 0·66$), a significant inverse association was only evident in cross-sectional studies (RR 0·78, 95 % CI 0·68, 0·88) but not in prospective cohort studies (RR 0·83, 95 % CI 0·64, 1·06). The non-significant inverse association in prospective cohort studies was possibly driven by the only study[28] showing a tendency towards positive association (RR 1·21, 95 % CI 0·90, 1·62), as the association became significant after exclusion of the present study (RR 0·74, 95 % CI 0·57, 0·98). There was no evidence of publication bias ($P_{\text{Begg's}} = 0·14$; $P_{\text{Egger's}} = 0·25$).

Table 1. Selected participant characteristics according to milk consumption
(Mean values and standard deviations; numbers and percentages)

	Consumers (n 905)		Non-consumers (n 4244)		
	Mean	SD	Mean	SD	P
Demographic characteristics					
Age (years)	50·17	9·34	54·78	9·56	<0·001
Sex					<0·001
Men					
n	314		2012		
%	34·7		47·4		
Women					
n	591		2232		
%	65·3		52·6		
Education level					<0·001
<High school					
n	804		4025		
%	89·0		94·8		
High school or vocational school					
n	84		199		
%	9·2		4·7		
≥College					
n	17		20		
%	1·8		0·5		
Behavioural characteristics					
Physical activity (min/d)	49·21	32·26	40·81	26·04	<0·001
Alcohol intake					<0·001
0/week					
n	754		3357		
%	18·3		81·7		
1–3/week					
n	89		371		
%	19·3		80·7		
>3/week					
n	53		475		
%	10·0		90·0		
Smoking status					<0·001
Never					
n	711		2975		
%	78·6		70·1		
Former					
n	23		76		
%	2·5		1·8		
Current					
n	171		1193		
%	18·9		28·1		
Sleep duration (h/d)	7·26	1·03	7·33	0·99	0·082
Television watching duration (h/d)	4·81	2·74	4·21	3·01	<0·001
Food groups (g/d)					
Red meat	52·92	44·57	59·27	46·66	<0·001
Poultry	44·71	50·80	51·53	47·68	<0·001
Fish	64·82	79·84	69·76	55·79	0·077
Fruits	132·09	108·74	109·77	101·86	<0·001
Vegetables	317·96	125·88	323·25	146·10	0·313
Soya	40·18	50·54	52·69	59·55	<0·001
Nuts	11·69	18·86	7·15	16·52	<0·001
Salted vegetables	20·35	29·34	22·68	27·64	0·024
Metabolic markers					
Body weight (kg)	60·42	9·50	61·67	10·04	<0·001
BMI (kg/m^2)	23·34	2·97	23·95	3·11	<0·001
Waist circumference (cm)	80·29	8·21	81·89	8·52	<0·001
TAG (mmol/l)	1·55	1·29	1·57	1·16	0·798
HDL-cholesterol (mmol/l)	1·37	0·30	1·33	0·32	0·001
LDL-cholesterol (mmol/l)	2·72	0·73	2·83	0·74	<0·001
Systolic BP (mmHg)	124·78	16·64	127·58	17·65	<0·001
Diastolic BP (mmHg)	79·35	10·77	80·79	11·23	<0·001
Glucose (mmol/l)	5·79	1·41	5·73	1·02	0·214

BP, blood pressure.

Table 2. Prevalence of the metabolic syndrome and its components according to milk consumption
(Numbers and percentages; odds ratios and 95 % confidence intervals)

	Non-consumers (*n* 4244)			Consumers (*n* 905)		
	OR		95 % CI	OR		95 % CI
Metabolic syndrome						
n		2018			369	
%		47·5			40·8	
Unadjusted	1		Ref.	0·76		0·66, 0·88
Multivariable*	1		Ref.	0·86		0·73, 1·01
Elevated waist circumference						
n		2583			482	
%		60·9			53·2	
Unadjusted	1		Ref.	0·73		0·63, 0·85
Multivariable*	1		Ref.	0·78		0·67, 0·92
Elevated TAG						
n		1279			249	
%		30·1			27·5	
Unadjusted	1		Ref.	0·88		0·75, 1·03
Multivariable*	1		Ref.	0·83		0·70, 0·99
Reduced HDL-cholesterol						
n		2333			549	
%		54·9			60·6	
Unadjusted	1		Ref.	1·26		1·09, 1·46
Multivariable*	1		Ref.	1·14		0·96, 1·36
Elevated blood pressure						
n		2142			394	
%		50·5			43·5	
Unadjusted	1		Ref.	0·76		0·66, 0·87
Multivariable*	1		Ref.	0·85		0·73, 0·99
Elevated blood glucose						
n		1969			366	
%		46·4			40·4	
Unadjusted	1		Ref.	0·79		0·68, 0·91
Multivariable*	1		Ref.	0·99		0·82, 1·20

Ref., referent.
* Multivariable model was adjusted for age, sex, education, smoking, alcohol, physical activity, sleep duration, television watching duration, BMI, and consumption of red meat, poultry, fish, fruits, vegetables, nut, soya and salted vegetables.

The association between the highest *v.* lowest categories of milk consumption and the metabolic syndrome components is shown in Fig. 2. In the analyses of the metabolic syndrome components[18,21–24], high milk consumption was inversely associated with elevated waist circumference (RR 0·84, 95 % CI 0·77, 0·91), elevated blood pressure (RR 0·90, 95 % CI 0·82, 0·98) and elevated TAG (RR 0·82, 95 % CI 0·76, 0·89) but not with elevated fasting blood glucose (RR 0·95, 95 % CI 0·82, 1·10) and reduced HDL-cholesterol (RR 0·86, 95 % CI 0·71, 1·03). When the analyses were restricted to the Asian studies[21–24], high milk consumption was inversely associated with elevated waist circumference (RR 0·83, 95 % CI 0·76, 0·90), blood pressure (RR 0·87, 95 % CI 0·76, 0·99), elevated TAG (RR 0·83, 95 % CI 0·73, 0·88) and reduced LDL-cholesterol (RR 0·82, 95 % CI 0·69, 0·97) but not with fasting blood glucose (RR 0·95, 95 % CI 0·80, 1·13).

Discussion

The present study

In the present cross-sectional studies of 5149 residents of Suzhou Industrial Park, there was no significant difference in the odds of having the metabolic syndrome between milk consumers and non-milk consumers. However, milk consumers had lower odds of having elevated waist circumference, elevated TAG and elevated blood pressure than non-milk consumers.

The results of the present study should be treated within the context of the following caveats. First, the cross-sectional design of our study limits the ability to infer causal relationships between milk consumption and the metabolic syndrome and its components. Second, the low consumption of milk among the participants of our study did not allow more meaningful analyses according to the categories of milk consumption or the fat content of milk. Third, the validity of the observed findings is dependent on our ability to control for confounding factors. In our study, milk consumption appeared to be a reflection of healthier lifestyles and eating habits that may contribute to the prevention of the metabolic syndrome[1]. Notably, milk consumers were more likely to be physically active and drink less alcohol, less likely to be current smokers, had a higher consumption of fruit and nut and had a lower consumption of red meat. The observed inverse association between milk consumption and the metabolic syndrome in the unadjusted model became statistically non-significant in the multivariable model, suggesting that the inverse association between milk consumption and the metabolic syndrome in our study population could partially be explained by the difference in lifestyle

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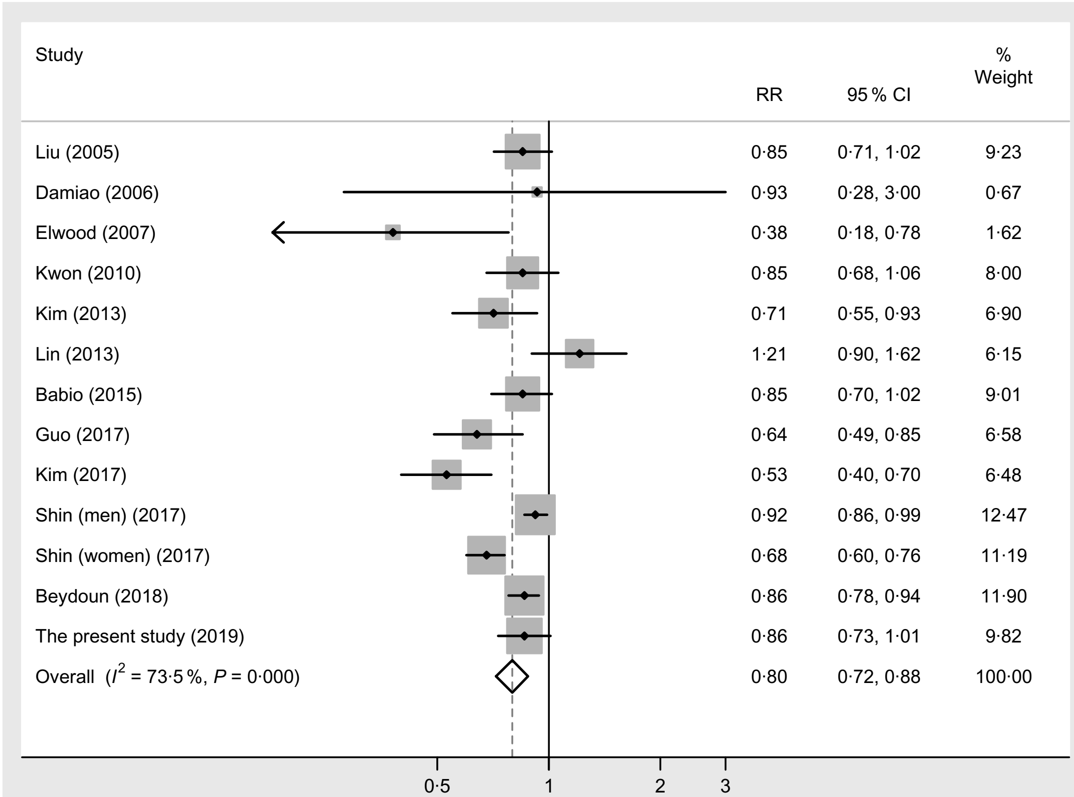

Fig. 1. Forest plot of the association between the highest *v.* lowest categories of milk consumption and the metabolic syndrome. Weights are from random-effects analysis. RR, relative risk.

and dietary characteristics between milk consumers and non-milk consumers. Although a wide range of covariates have been taken into account in the multivariable model, we did not have the information on important dietary factors, including total energy intake and dietary nutrient intake (e.g. carbohydrate, protein, fat, cholesterol, vitamin, mineral and fibre). It is known that dietary energy density[36,37] and the intake of certain nutrients[1,38–44] are associated with the metabolic syndrome. Thus, our inability to consider such factors in our analyses may have resulted in unmeasured or residual confounding. Finally, dietary consumption was assessed with a FFQ. The accuracy of information obtained with a FFQ is dependent on the memory and sincerity of the participants. For example, people tend to overestimate the intake of foods perceived as healthy and underreport the intake of foods perceived as less healthy[45]. Several fatty acids (C14 : 0, C15 : 0, C17 : 0 and *trans*-C16 : 1*n*-7) have been used as biomarkers of dairy intake[46–48] to overcome the shortcomings of FFQ. Combining the classic dietary assessment with validated dairy biomarkers may improve the robustness of dietary assessment in epidemiological studies. Of interest, dairy fat biomarkers have been shown to have a neutral association with the incidence of CVD[47] and an inverse association with the incidence of type 2 diabetes mellitus [48]. To the best of our knowledge, no studies have investigated the associations between these fatty acids and the metabolic syndrome; this possibility warrants further study.

Nearly all of the Asian studies investigating the association between milk consumption and the metabolic syndrome were conducted in South Korea. The present study adds to the limited evidence available on the association between milk[29,30] or dairy product[20,49] consumption and the metabolic syndrome in Chinese populations. A small-scale study[30] in Yuci District (Jinzhong City, Shanxi Province) indicated that participants who rarely consumed milk had higher odds of having the metabolic syndrome compared with participants who often consumed milk. A nationally representative cross-sectional survey[50] using data from the China Health and Nutrition Survey 2009 identified low daily consumption of milk and dairy product as one of the dietary factors that correlated with increased numbers of the metabolic syndrome components in women. By comparison, the China National Nutrition and Health Survey 2010–2012[20] showed that dairy consumption was not significantly associated with the metabolic syndrome in both men and women. A matched case–control study[49] of policemen demonstrated an inverse association between dairy product consumption and the metabolic syndrome. A multi-ethnic cross-sectional study[29] in rural Xinjiang found that participants whose consumption of ≥1·5 litres fresh milk per week was associated with 36 % lower odds of having the metabolic syndrome. Unlike our study, all previous Chinese studies[20,29,30,49] only investigated the metabolic syndrome but did not consider the extent to which milk or dairy product consumption may influence the metabolic syndrome components. In the present study,

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Table 3. Subgroup and meta-regression analyses of the association highest *v.* lowest categories of milk consumption and the metabolic syndrome
(Numbers; relative risks (RR) and 95 % confidence intervals; I^2)

	No. of studies	RR	95 % CI	I^2 (%)	$P_{meta\text{-}regression}$
Overall	11 + 1	0·80	0·72, 0·88	73·5	–
Design					
Prospective cohort	5	0·83*	0·64, 1·06	86	0·66
Cross-sectional	6 + 1	0·78	0·68, 0·88	75	
Study populations					
Western	5	0·84	0·77, 0·93	15·1	0·94
Asian	6 + 1	0·78	0·67, 0·91	83	
Criteria					
NCEP ATP III	6	0·84	0·70, 0·99	70	
JIS	4 + 1	0·78	0·68, 0·90	79·2	0·27
Adjustment for confounders					
Energy intake					
Yes	9	0·77	0·68, 0·87	77·4	0·37
No	2 + 1	0·86	0·71, 1·05	69	
Vegetable consumption					
Yes	4 + 1	0·86	0·76, 0·98	58·4	0·26
No	7	0·74	0·63, 0·87	80	
Fruit consumption					
Yes	2 + 1	0·86	0·80, 0·92	0	0·44
No	9	0·76	0·66, 0·89	80	
BMI					
Yes	7 + 1	0·74	0·61, 0·89	87	0·37
No	4	0·84	0·75, 0·95	51	
Physical activity or exercise					
Yes	8 + 1	0·81	0·72, 0·92	75·5	0·41
No	3	0·68	0·48, 0·96	76	
Alcohol					
Yes	10 + 1	0·81	0·73, 0·89	73	–
No	1	0·38	0·18, 0·78	–	
Smoking					
Yes	10 + 1	0·79	0·71, 0·88	76	–
No	1	0·85	0·71, 1·02	–	

NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; JIS, Joint Interim Statement.
* RR after excluding a study[28] that reported conflicting result yielded was 0·74 (95 % CI 0·57, 0·98).

the significant inverse association appeared to be confined to elevated waist circumference, elevated TAG and elevated blood pressure, as no association was found for elevated fasting glucose and reduced HDL-cholesterol. Of interest, a few studies[51–53] have investigated the association between milk or dairy consumption and cardiometabolic conditions in the Chinese population. A recent large cross-sectional study[51] of Northern Chinese populations investigating the association between dairy consumption and cardiometabolic conditions showed that higher dairy consumption was inversely associated with the prevalence of overweight, obesity, central obesity and hyperlipidaemia but not with the prevalence of diabetes and hypertension. A prospective study[52] concluded that dairy consumption was significantly associated with a lower risk of type 2 diabetes mellitus and favourable changes in fasting blood glucose, waist circumference, BMI and systolic and diastolic blood pressure among middle-aged and older Chinese in Beijing and Shanghai. Another prospective cohort study[53] indicated that higher consumption of fresh milk and powdered milk was associated with a lower risk of developing type 2 diabetes mellitus in Shanghai women. Briefly, the evidence in Chinese populations, while limited, suggests that consuming milk and dairy product consumption as part of a healthy balanced diet might contribute to the prevention of some of the most prevalent cardiometabolic conditions related to lifestyle and eating habits.

According to the Chinese dietary guidelines (2016)[54], Chinese residents are recommended to consume 300 g of milk and dairy products per d. Unfortunately, the average consumption of milk and dairy products Chinese people in general consume was far below the recommended levels. According to the data from China Health and Nutrition Surveillance 2010–2012[25], the average consumption of milk and dairy products in big city, small- and medium-sized city, normal rural area and poor rural area was 64·3, 24·2, 9·1 and 4·9 g/d, respectively, with only 23·7 % of the whole populations consumed milk and dairy products daily. Similarly, the average milk consumption in our study was only approximately 20 g/d, with 80 % of the total study populations did not consume milk. As the overall dairy consumption in China is expected to increase over the next few years[55], future nationwide surveys may have more power to refine the current evidence on this topic.

Meta-analysis of the present study and published observational studies

Studies investigating the association between milk consumption and the metabolic syndrome have yielded inconsistent results,

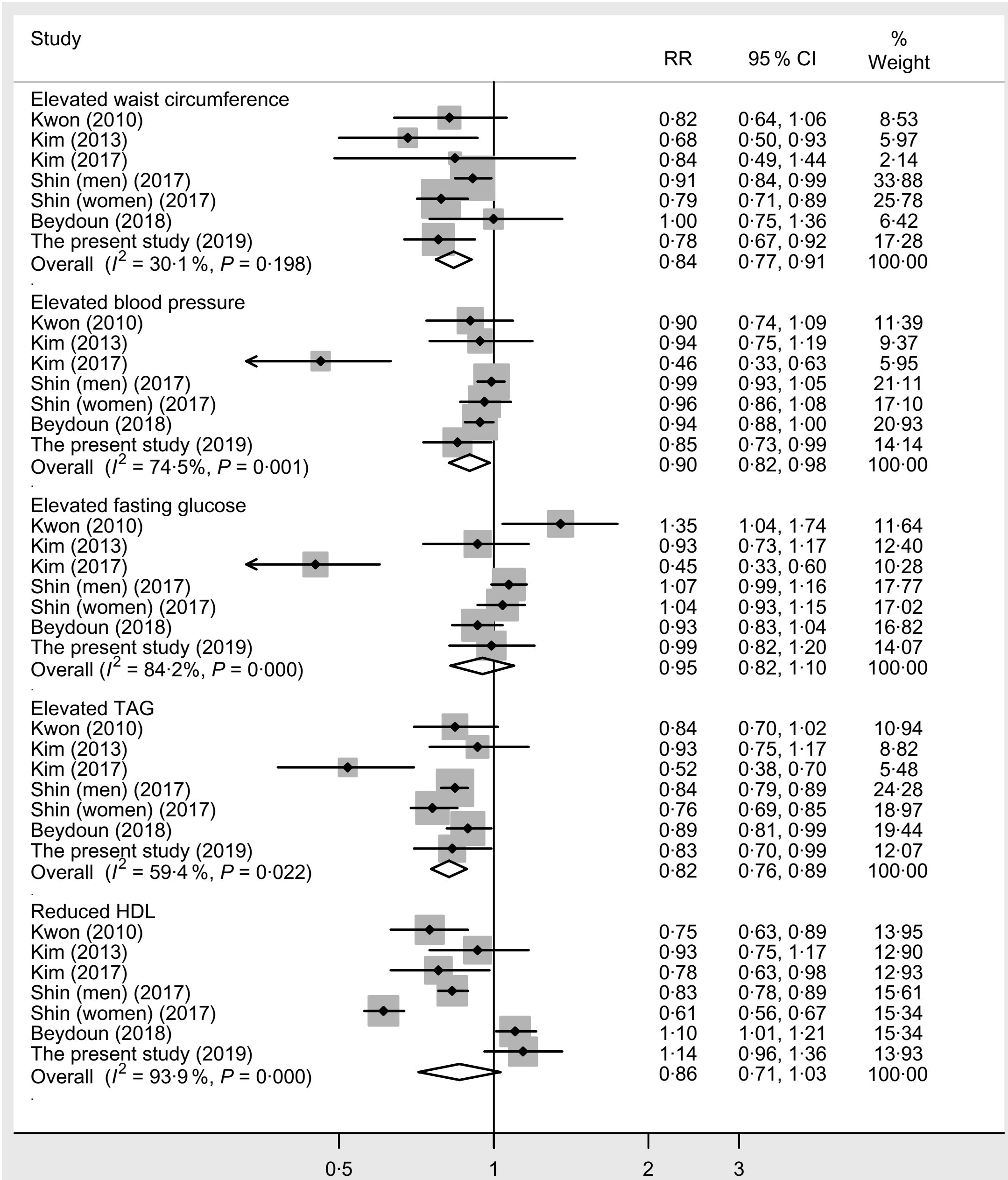

Fig. 2. Forest plot of the association between the highest *v.* lowest categories of milk consumption and metabolic syndrome components. Weights are from random-effects analysis. RR, relative risk.

possibly due to the differences in the study design, the metabolic syndrome definition and cultural characteristics and dietary patterns underlying study populations. When the results of our study were pooled together with other published observational studies, high milk consumption was inversely associated with the metabolic syndrome and its components (except elevated fasting blood glucose).

The majority of studies included in our meta-analysis had a cross-sectional design[15,16,21,22,24,29], with only a few prospective cohort studies[17,18,23,27,28]. In general, a clear tendency towards an inverse association (RR ranged from 0·38 to 0·93) was evident in all studies, with the exception of a tendency towards positive association (RR 1·21) observed in a study[28] among community-dwelling elderly in Taiwan. The inverse association was observed in both cohort and cross-sectional studies, although this association did not reach statistical significance in cohort studies. The non-significant finding in cohort studies appeared to be largely driven by the study mentioned above[28], as the inverse association became significant after the omission of the present study from the analysis.

The included studies used National Cholesterol Education Program Adult Treatment Panel III (including modified version) criteria or JIS criteria. Notably, while both National Cholesterol Education Program Adult Treatment Panel III [56] and JIS[31] define the metabolic syndrome as the presence of three of the five cardiometabolic factors (elevated waist circumference, elevated TAG, reduced HDL-cholesterol, elevated blood pressure and elevated fasting blood glucose), the cut-points to define elevated fasting blood glucose ($\geq$6·1 mmol/l *v.* $\geq$5·6 mmol/l) and elevated waist circumference (if not modified according to populations or ethnic groups) are higher according to National Cholesterol Education Program Adult Treatment Panel III criteria than according to JIS criteria. If the higher cut-points were used, fewer individuals could be diagnosed as having the metabolic syndrome than if the lower cut-points were used. Nonetheless, our results indicated that the study criteria did not appear to modify the observed association.

Rapid globalisation, urbanisation and economic growth among developing countries have led to the dietary transition from traditional whole foods, plant-based diet to the 'Western' diet high in processed foods, sweetened foods and animal sources foods[57]. In this case, although milk and dairy product consumption is generally still higher in Western populations than in Asian populations, milk and dairy product consumption has been increasing in Asian countries, particularly in China[55]. Thus, the present study and other Asian studies provide relevant and timely insights into the association between milk consumption and the metabolic syndrome, which may contribute to public health intervention in Asian countries that are affected by the dietary transition. Our subgroup analyses indicated that high milk consumption was inversely associated with the metabolic syndrome in Asian populations and Western populations.

There are several limitations to consider when interpreting the results of the meta-analysis of observational studies. First, although the results of the meta-analysis of observational studies are encouraging, the limited available data from prospective cohort studies preclude solid conclusions regarding the potential role of milk in the prevention of the metabolic syndrome. Second, the high heterogeneity across studies indicates that the results of the present meta-analysis should be interpreted with caution. The heterogeneity was low in studies that adjusted for Western populations and in studies that adjusted for fruit intake. Nonetheless, nearly all studies included in the present meta-analysis showed a tendency towards an inverse association, suggesting that the observed heterogeneity was likely due to the difference in the strength of association (significant *v.* non-significant) rather than the direction of the association (inverse *v.* positive). Third, observational studies are subject to residual and unmeasured confounders that may influence the observed findings. Subgroup analyses revealed that the inverse association between high milk consumption and the metabolic syndrome remained significant in the studies that adjusted for energy intake, fruit consumption, vegetable consumption, physical activity or exercise, alcohol or smoking. Finally, all studies on this topic have relied on FFQ, which may subject to bias-related memory and sincerity.

Potential mechanisms

The inverse association between milk or dairy product consumption and the metabolic syndrome may be collectively or individually mediated by specific nutrients within milk and dairy products. There is emerging evidence that milk protein may have the potential to improve body composition[58], glucose metabolism[59] and lipid profile[3]. Milk protein and its derived peptides have been shown to reduce blood pressure, possibly via inhibition of angiotensin I-converting enzyme[4,60]. Ca, K and Mg in milk or dairy products may help regulate blood pressure homoeostasis via various mechanisms[2]. Additionally, Ca may improve lipid profile[61] and induce weight loss[62] through the potential mediation of increased faecal fat excretion. While low levels of vitamin D are found naturally in milk, fortified milk is an excellent source of vitamin D. Vitamin D deficiency has been implicated in the development of certain cardiometabolic conditions, such as obesity, diabetes and hypertension[63]. Although milk and dairy products are nutrient-rich foods, high-fat milk and dairy products are also a major source of cholesterol-raising SFA, which have been considered to be involved in the pathogenesis of CVD. The currently available evidence, while inconclusive, suggests that high-fat milk and dairy product consumption may not be associated with increased risks of CVD and other cardiometabolic conditions[59,64]. The results from three cohorts of American adults[65] showed that dairy fat was not associated with an increased risk of CVD. However, replacing dairy fat with plant-based fat or PUFA was associated with a lower risk of CVD, suggesting that dairy fat may not be an optimal type of fat in the human diet. In this sense, although consuming high-fat dairy products in moderation may not be associated with an increased risk of CVD and other cardiometabolic conditions[59,64], consuming low-fat dairy products is preferable to limit saturated fat intake but still offers decent amounts of nutrients.

Conclusions

In summary, the currently available evidence suggests that higher milk consumption is inversely associated with the metabolic syndrome. Nonetheless, this evidence was mainly based on cross-sectional studies, and additional data from prospective cohort studies are warranted to determine the direction and shape of the association between milk consumption, preferably stratified by fat content (high-fat milk and low-fat milk), and subsequent metabolic syndrome risk across different subpopulations and genetic variations. Finally, it is also important to answer the question of whether replacing milk with non-dairy plant-based milk alternatives (e.g. soya, rice, oat, almond, hazelnut and coconut) and vice versa may improve cardiometabolic health to a greater extent.

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The authors Y.-J. S. and B. L. are affiliated with Jinshan Branch Company, Inner Mongolia Yili Industrial Group Co. Ltd. in China. The authors K. H., L.-G. Y., J.-R. Y., X.-Y. Z., H. Z. and L.-Q. Q. state that they have no potential conflicts of interest.

Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S0007114520000227

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