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Dietary patterns and their associations with the metabolic syndrome and predicted 10-year risk of CVD in northwest Chinese adults

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Abstract

The impact of diet on the metabolic syndrome (MetS) and CVD has been investigated widely, but few studies have investigated the association between dietary patterns (DP) and the predicted CVD, derived from reduced rank regression (RRR). The objectives of this study were to derive DP using RRR and principal component analysis (PCA) and investigate their associations with the MetS and estimated 10-year atherosclerotic CVD (ASCVD). We used the baseline dataset from the Xinjiang multi-ethnic cohort study in China, collected from June 2018 to May 2019. A total of 14 982 subjects aged 35–74 years from Urumqi, Huo Cheng and Mo Yu were included in the analysis. The 10-year ASCVD risk was estimated using the Chinese ASCVD risk equations. The associations of DP with the MetS and 10-year ASCVD were determined using multivariable logistic regression models. In Urumqi and Mo Yu, the increased RRR DP score was associated with a higher OR of having the MetS and with a higher OR of elevated 10-year ASCVD risk. However, only the first DP determined by PCA in Urumqi was inversely associated with the MetS and elevated 10-year ASCVD risk. The prevalence of the MetS and elevated ASCVD risk in urban population is higher than that in rural areas. Our results may help nutritionists develop more targeted dietary strategies to prevent the MetS and ASCVD in different regions in China.

Key words: Dietary patterns: Reduced rank regression: Principal component analysis: Metabolic syndrome: CVD

The metabolic syndrome (MetS) is a cluster of metabolic abnormalities that have been associated with an increased risk of developing CVD[(1)]. Based on the findings from the China National Health and Nutrition Surveillance (2010–2012), the overall prevalence rate of the MetS among Chinese adults was 11·0 %[(2)]. It has been estimated that men with the MetS have a 3-fold increased risk of CVD[(3)]. Atherosclerosis is the underlying disease process that may result in atherosclerotic CVD (ASCVD) including myocardial infarction, ischaemic stroke and peripheral arterial disease[(4)].

Due to the increasing prevalence of metabolic diseases such as obesity and diabetes, ASCVD has been globally considered a serious public health issue. In 2018, an estimated 290 million people had CVD and they are also the number one cause of mortality in China, accounting for more than 40 % of all deaths[(5)]. Given the human burden of ASCVD, risk assessment provides guidance to clinicians in preventive interventions. Most risk prediction models derived primarily from Western populations, such as the Pooled Cohort Equations (PCE)[(6)], might not be suitable for direct application in other ethnic populations. Therefore, in 2016, the sex-specific prediction for ASCVD risk in China (China-PAR) equations for 10-year risk prediction of ASCVD was successfully developed and validated for the Chinese population[(7)].

Among the influencing factors of CVD, healthy eating has been implicated as a preventive behaviour to reduce the risk of CVD[(8–9)]. Furthermore, an overall healthy dietary pattern (DP) has also been shown to be associated with reduced CVD risk[(10)]. Information on mediating pathways/risk factors in diet–disease studies may provide a better understanding of the role of diet in disease development. Cardiometabolic traits, including the components of the MetS, are typically important predictors for CVD, but have also been implicated in carcinogenics[(11)]. Reduced rank regression (RRR) can be used to derive DP that maximally explain variation in a set of predetermined response variables, typically intermediates related to disease risk.

Abbreviations: ASCVD, atherosclerotic CVD; China-PAR, prediction for ASCVD risk in China; DBP, diastolic blood pressure; DP, dietary pattern; MAP, mean arterial blood pressure; MetS, metabolic syndrome; PCA, principal component analysis; RRR, reduced rank regression; SBP, systolic blood pressure; SES, social economic status; WC, waist circumference.

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Because an *a priori* hypothesis can be incorporated in the form of response variables, derived DP may be more readily linked to biological pathways relevant for disease aetiology[12]. This is the advantage of RRR over traditional diet pattern principal component analysis (PCA)[13]. DP derived using PCA tend to explain a high proportion of the variability in dietary intake and hence describe actual DP of the population[14].

DP are different by geographical, region, ethnicity, economic status and culture[15–16]. Located in the northwestern border of China, Xinjiang is the largest provincial administrative region in China with an area of 1·66 million square km, accounting for one-sixth of China's total land area. It is customary to call the south of the Tianshan Mountains, south Xinjiang, and the north of the Tianshan Mountains, north Xinjiang. As a multi-ethnic area, forty-seven ethnic groups live here. For a long time, complex and diverse dietary structures and habits have been formed and different levels and types of dietary imbalances have resulted in different prevalence rates of some chronic diseases. At the same time, the imbalance of economic development has caused widespread malnutrition and micro-nutrient deficiencies in rural areas, especially in poor rural areas. According to the International Diabetes Federation criteria, the age-standardised prevalence of the MetS in Xinjiang was 21·33 %[17]. To the best of our knowledge, since the establishment of the China-PAR in 2016, it has not been used to predict 10-year risk of ASCVD in Xinjiang population. Few studies have looked at the association of DP with the MetS and the predicted 10-year risk of ASCVD in Xinjiang Uyghur population[18], and none has used RRR. The present studies on DP related to metabolic disorders using the RRR method are mainly carried out in European and American populations. Given the unique and novel strengths of the RRR methodology and its limited application to nutritional epidemiology to date, further studies are needed to improve our understanding of the relationship between RRR-derived DP and the MetS and estimated risk of ASCVD. Furthermore, the role of area differences in diet with respect to the association with the MetS and ASCVD is still uncertain.

Therefore, the aims of this study were to identify DP associated with blood metabolism biomarkers and to evaluate the association of DP with the MetS and the predicted 10-year risk of ASCVD in this multi-ethnic population in three different study sites, in northwest China.

Methods

Study design and study population

The Xinjiang multi-ethnic cohort study (CNC) is a population-based, prospective cohort established from April 2018 to May 2019. A non-probability sampling design method was used to select three specific areas in Xinjiang based on their socio-economic status, geographical location and ethnic distribution: Urumqi, Huo Cheng and Mo Yu. As the capital city of Xinjiang, Urumqi has a relatively developed economy. Huo Cheng is located in northern Xinjiang, which is a multi-ethnic living area. Mo Yu is located in southern Xinjiang, about 1450 km away from Urumqi, and the economy is more backward than other areas of Xinjiang. A total of 30 949 adults, aged 35–74 years, were enrolled. For the present study, we included only those participants of the CNC with complete information regarding cardiometabolic traits. We excluded any subject with acute myocardial infarction or stroke and/or diabetes mellitus (based on self-reported diabetes mellitus at baseline and/or use of anti-diabetic drugs). Therefore, 14 982 subjects (6098 males and 8884 females) with complete data on diet and cardiometabolic risk factors were included in this study. Informed consent was obtained from all participants, who were then interviewed in person using structured questionnaires. The study was approved by the institute of traditional Chinese medicine of Xinjiang Uyghur autonomous region (2018XE0108). Detailed information about the CNC study design has been described elsewhere[19] (Fig. 1).

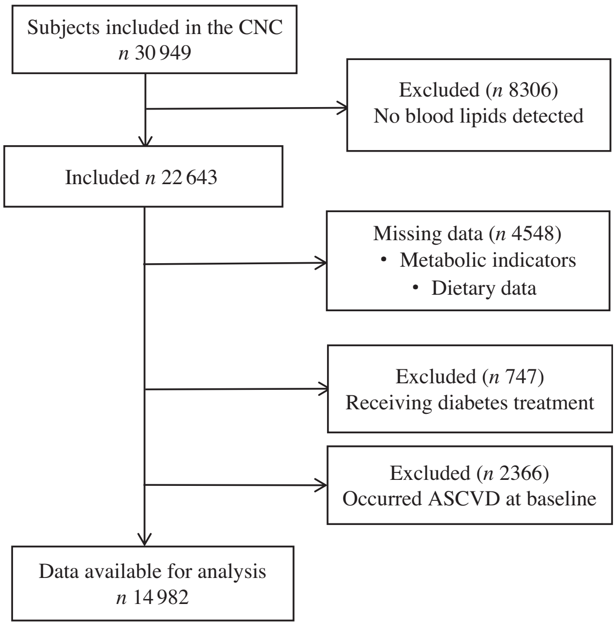

Fig. 1. Flow diagram of subjects included in the Xinjiang multi-ethnic cohort study (CNC). ASCVD, atherosclerotic CVD.

Laboratory measurements

Each participant was invited to provide a fasting blood sample. Fasting blood glucose was measured in whole blood, and TAG, total cholesterol, HDL-cholesterol and LDL-cholesterol were measured in serum. The health service centres of each village in the three survey sites were responsible for the blood glucose and blood lipid detection by automatic biochemical analyzer. The test methods and requirements are based on the national clinical test operating procedures[20].

Dietary assessment

Habitual diet over the past year was assessed using the interviewer-administered FFQ. Referring to the dietary questionnaire of natural population cohort study in northwest China and combining the characteristics of Xinjiang diet, the final FFQ included 127 foods items. The 127 food items were aggregated into thirty food groups based on the similarity of nutrient composition and culinary usage. The food items and six food categories: Staple food, including rice, wheat and whole grains; Animal food, including pork, lamb, beef, poultry and products, seafood products, eggs and products of animal viscera, such as offal; Plant-based food, including fresh vegetables, fresh fruits, potato, beans and products; Dairy products, including milk, yogurt, other dairy products, butter tea and milk tea; Other food, including pickled/dried vegetables, nuts, red dates, gouji berries, raisins and dried fruits; Soft drinks, including soya milk, pure juice, carbonated drinks and other sugary drinks. For each food item, participants reported the frequency of habitual consumption but not quantities of food consumption. The frequency of intake was measured using five categories: daily, 4–6 times a week, 1–3 times a week, 1–3 times a month, never or rarely. This FFQ has not been validated yet.

Metabolic syndrome assessment

The MetS was defined according to the Chinese Diabetes Society criteria[21]. The presence of ≥3 of the following metabolic risk factors: (1) abdominal obesity: male waist circumference (WC) ≥90 cm and female WC ≥ 85 cm; (2) hypertension: systolic blood pressure/diastolic blood pressure (SBP/DBP) ≥130/85 mmHg; (3) high triacylglycerolaemia: TAG ≥ 1·70 mmol/l; (4) low high-density lipoproteinaemia: fasting HDL-cholesterol < 1·04 mmol/l; (5) hyperglycaemia: fasting blood glucose ≥ 6·1 mmol/l.

Estimated 10-year atherosclerotic CVD risk

The predicted 10-year risk of a first ASCVD event for adults aged 35–74 years was calculated using the China-PAR equation and included the following variables: age (years), concentration of total cholesterol (mmol/l), HDL-cholesterol (mmol/l), treated or untreated SBP (mmHg), diabetes status (defined here as physician diagnosis), self-reported smoking status (yes, no), BMI, WC, geographic region (northern China, southern China), urbanisation (urban, rural) and family history of ASCVD (yes, no). Participants with an ASCVD score of >5 % were considered to be at high risk for future ASCVD events. The China-PAR equation has been validated and applied in previous studies[22–23].

Covariate assessment

Weight, height and WC were measured by investigators using standard methods. Weight and height were measured, while the participants were marginally clothed, without shoes using an SK-X80 (Sonka Corporation) and recorded to the nearest 0·1 kg and 0·1 cm. The BMI was calculated as weight in kg divided by the square of height in metres. The WC was measured to the nearest 0·1 cm at the midpoint between the lower rib and the iliac crest, at the end of normal expiration, while the participants were standing. Blood pressure was measured using a standard mercury sphygmomanometer with the cuff on the right upper arm after 5 min of rest. Two blood pressure readings taken 5 min apart were recorded, and the mean of the two readings was calculated for SBP and DBP, together with the mean arterial blood pressure (MAP). Face-to-face interviews were conducted by investigators trained in administering the study questionnaires. Investigators used a standardised questionnaire to collect information regarding the participants' demographic characteristics, current smoking status, current drinking status, physical activity, medical history and medication use. Social economic status (SES) has a measurable and significant impact on cardiovascular health. Individuals with low SES carry a substantial burden of CVD and are more likely to experience increased event rates and poorer outcomes[24]. In our study, SES data included information regarding education: no formal education, elementary, middle school, high school or higher, level of education; Occupation: unemployed, laid-off, houseworker, farmer, sales and service staff/worker, private owners, professional skilled worker or administrative and management personnel; Household assets (0–1, 2–3, ≥4); Income (<10 000, 10 000–34 999, ≥34 999). These variables were used to construct a SES sum score, in accordance with a previous study in China[25]. The score ranges from 0 to 11 points and comprises the domains education, occupation, income and household assets. The exact procedure of the construction is depicted in online Supplementary Table S1.

Statistical analysis

Data reduction techniques using RRR and PCA were used to derive DP. Using PCA, a similar number of factors (thirty factors) to food groups were produced. However, we retained eleven factors, of which the first two were chosen based on scree plot, eigenvalues (>2) and interpretability. Varimax rotation was applied to attain optimal structure and increase the interpretability of factors. Factor scores for each of the participants and the retained factors were calculated as the sum of the products of factor loading coefficients, which was standardised by the daily intake of each food item. Sample adequacy was checked using the Kaiser–Mayer–Olkin (KMO) test.

In the RRR model, five components of the MetS (HDL-cholesterol, TAG, fasting blood glucose, WC and MAP) were the dependent variables (Yi) and were used simultaneously in the model, and the thirty food groups (Xi) were the independent variables. The statistical model can be expressed as $\mathrm{Yi} = \alpha + \beta \times \mathrm{Xi} + \epsilon$, where ϵ is the random error. Briefly, RRR extracts linear combinations (the so-called factors or DP) of predictor variables (e.g. food intakes) that explain as much variation in response variables (e.g. biomarkers of disease), as possible. We used the primary DP for subsequent analyses because it explained the largest amount of variation in MetS components[26]. For the development of DP, we adjusted blood pressure levels in participants who reported taking any blood pressure-lowering drugs by adding a correction constant (systolic blood pressure +15 mmHg; diastolic blood pressure +10 mmHg)[27]. Since there was no adjusted criterion to account for the effect of the medication on fasting blood glucose[28], we excluded all participants who self-reported using medication for diabetes (n 747) for the RRR analysis. A score for each participant for the primary RRR DP was calculated as the weighted sum of the thirty food groups, with each food group weighted according to its respective factor load value[29].

Finally, we performed multivariate logistic regression analyses to evaluate associations between DP and the MetS and predicted 10-year ASCVD risk, with adjustment for potential confounding variables, such as age, sex, race, living area, SES, smoking status, alcohol consumption (never, occasional, habitual) and physical exercise (never, occasional, habitual). Trends across the quartiles were examined using ordinal variables for DP score and likelihood ratio test. All data analyses were conducted using SAS version 9.4. Statistical significance was defined as a P value < 0·05 in two-sided test.

Results

The social-demographic characteristics and lipid profiles of participants by study site are presented in Table 1. The participants from Urumqi were older than those from Huo Cheng and Mo Yu. Urumqi participants had the highest percentage of highly educated individuals, alcohol drinkers, were most physically active and had the highest metabolic profiles. The highest percentage of current smokers and the highest BMI scores were found in the Huo Cheng participants, whereas the participants had the highest WC. The prevalence of the MetS and the predicted 10-year ASCVD risk was significantly higher in Urumqi participants than in those participants from Huo Cheng and Mo Yu.

The main factor loadings of the three retained patterns derived by the three methods are presented in Table 2. A high positive loading indicates a strong direct association between the food group and the pattern, whereas a high negative loading reflects a strong inverse association. The RRR-derived DP for Urumqi was characterised by greater intake of milk tea and by lower intake of yogurt, gouji berries, red dates, dried vegetables, nuts, eggs, fishes, seafood, whole grains and soyabean milk. The major contributors to the first PCA pattern in Urumqi were rice, beef, vegetables, nuts, red dates and gouji berries, all of which were positively correlated with the pattern score. Factor 2 based on the PCA was characterised by high positive loadings of milk, yogurt, eggs and soyabean milk. The RRR-derived DP for Huo Cheng participants was characterised by positive loadings of lamb, milk products, milk tea, fruits and nuts and by negative loadings of beef and fishes/seafood. The first PCA pattern had high positive loadings of beef, beans, pickles and dried vegetables and had negative loadings of lamb. Factor 2 of the PCA was characterised by high positive loadings of pasta, fruit, potatoes, milk tea, as well as by a negative loading of whole grains. The RRR-derived DP for Mo Yu was characterised by positive loadings of whole grains and red dates and by negative loadings of beans, gouji berries, nuts, rice, milk and milk product and pure juice. Factor 1 of the PCA was characterised by high consumption of pasta, lamb, animal innards and pure fruit juice. The second PCA pattern had high positive loadings of eggs, nuts, red dates and raisins. In general, food groups showed lower factor loadings on RRR patterns, resulting in fewer important food groups.

The RRR-derived DP for Urumqi participants explained 1·43 % of the variation in the metabolic profile (explained 3·27 % of the variation in the MAP and 3·13 % of the WC). Using PCA, 25·95 % of variation in predictors (thirty food groups) was found, compared with 7·42 % of RRR. The RRR-derived DP for Huo Cheng participants explained 1·59 % of the variation in the metabolic profile (explained 2·12 % of the variation in the MAP and 3·41 % of the HDL-cholesterol) and 8·35 % in the predictor variables. The two PCA DP explained 25·55 % of total variance among thirty food groups. The RRR-derived DP for Mo Yu participants explained 1·08 % of the variation in the metabolic profile (explained 2·14 % of the variation in the MAP and 2·35 % of the WC) and 5·79 % in the predictor variables. Using PCA, 22·28 % of variation in predictors was found, compared with 5·79 % of RRR.

Online Supplementary Table S2 shows the baseline characteristics of the study population in different study sites by quartiles of DP. In Urumqi, participants in the highest quartile of the RRR-derived DP were more likely to be older, current smokers, higher SBP, DBP, WC and have very lower SES. In Huo Cheng, participants in the highest quartile of the RRR-derived DP were more likely to be younger, higher WC and HDL-cholesterol. In Mo Yu, participants in the highest quartile of the RRR-derived DP were more likely to be older, higher SBP, DBP, WC, TAG, HDL-cholesterol and have very lower SES.

Online Supplementary Fig. S1 presents the association between the number of MetS components and elevated ASCVD risk in participants in the three sites. As shown in this figure, with increasing in the components of MetS, the risk of ASCVD increases.

The association with the MetS for quartiles and per 1 SD of the DP score for the three study sites is presented in Table 3. A higher RRR DP score increased the odds for the MetS in Urumqi and Mo Yu. In Urumqi, the OR for the MetS in the highest quartiles compared with the lowest was 1·57 (95 % CI 1·26, 1·95), $P_{\text{for trend}} < 0{\cdot}001$ in the fully adjusted model. In Mo Yu, the OR for the MetS in the highest quartiles compared with the lowest was 1·23 (95 % CI 1·03, 1·48), $P_{\text{for trend}} < 0{\cdot}03$ in the fully adjusted model. In the analysis of the correlation between PCA DP and the MetS, only the negative correlation between the MetS and the first PCA DP in Urumqi was found (OR 0·93; 95 % CI 0·86, 0·99, $P_{\text{for trend}} = 0{\cdot}157$).

The association with predicted 10-year risk of ASCVD for quartiles and per 1 SD of the DP score for the three study sites is presented in Table 4. In Urumqi, the OR for the elevated 10-year ASCVD risk was 1·55 times higher in the highest quartiles compared with the lowest quartiles of the DP (OR 1·55; 95 % CI 1·13, 2·13, $P_{\text{for trend}} = 0{\cdot}001$). Per 1 SD increase of this DP, the estimated 10-year elevated ASCVD risk increased by 13 % (OR 1·30; 95 % CI 1·15, 1·47) in fully adjusted model. The DP was not associated with elevated 10-year ASCVD risk in Huo Cheng. In Mo YU, the OR for the elevated 10-year ASCVD risk was 1·63 times higher in the highest quartiles compared with the lowest quartiles of the DP (OR 1·63; 95 % CI 1·2, 2·08, $P_{\text{for trend}} < 0{\cdot}001$). Per 1 SD increase of this DP, the estimated 10-year elevated ASCVD risk increased by 12 % (OR 1·25; 95 % CI 1·14, 1·36) in fully adjusted model. The analysis of the association between PCA DP and predicted 10-year risk of ASCVD in different study sites also found that only the first PCA DP in Urumqi was a protective factor for ASCVD.

Discussion

The high worldwide burden of CVD and diabetes as the most common cause of mortality and morbidity has led many

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Table 1. Distribution of socio-demographic and CVD risk factors by site
(Numbers and percentages; mean values and standard deviations)

	Urumqi (*n* 4265)		Huo Cheng (*n* 3467)		Mo Yu (*n* 7250)			
Variables	*n*	%	*n*	%	*n*	%	F/χ^2	*P*
Age (years)							1129·97	<0·001
Mean	59·88		50·16		52·19			
SD	9·43		9·77		10·26			
Sex (females)	2635	61·8	1845	53·2	4404	60·7	70·33	<0·001
Ethnic group								
Han	3732	87·5	457	10·9	6	0·1	7470·10	<0·001
Uyghur	108	2·5	1028	29·7	7217	99·5		
Hui	360	8·4	1067	30·8	12	0·2		
Kazakh	28	0·7	912	26·3	15	0·2		
Other	37	0·2	3	0·1	0	0·0		
Education								
No formal education	464	10·9	814	23·5	1181	16·3	4145·90	<0·001
Elementary	1088	25·5	1639	47·3	5243	72·3		
Middle school	1496	35·1	771	22·2	736	10·2		
High school or higher	1217	28·5	243	7·0	90	1·2		
Physical activity								
Never	1734	40·7	2794	80·6	6942	95·8	5320·17	<0·001
Occasional	813	19·1	509	14·7	178	2·5		
Habitual	1718	40·2	154	4·7	130	1·7		
SES (very low)	716	16·8	1877	54·1	4428	51·1	4213·77	<0·001
Current smoking status	616	14·4	861	24·8	637	8·8	498·95	<0·001
Alcohol drinking status								
Never	3331	78·1	2870	82·8	5835	94·3	909·30	<0·001
Occasional	726	17·0	550	15·9	187	2·6		
Habitual	208	4·9	47	1·4	228	3·1		
Weight (kg)							418·40	<0·001
Mean	66·96		68·42		61·95			
SD	11·31		12·61		12·42			
Height (cm)							540·90	<0·001
Mean	161·89		161·29		157·06			
SD	8·26		9·00		8·44			
WC (cm)							93·57	<0·001
Mean	88·77		89·33		91·48			
SD	9·87		11·43		11·64			
SBP (mmHg)							321·49	<0·001
Mean	128·83		126·18		119·75			
SD	17·79		20·46		20·15			
DBP (mmHg)							204·60	<0·001
Mean	77·38		74·54		72·94			
SD	10·42		10·71		12·19			
TC (mmol/l)							95·71	<0·001
Mean	4·98		4·92		4·55			
SD	1·50		1·30		2·18			
HDL-cholesterol (mmol/l)							136·19	<0·001
Mean	1·51		1·33		1·34			
SD	0·52		0·76		0·53			
TAG (mmol/l)							135·25	<0·001
Mean	1·78		1·46		1·37			
SD	1·30		0·98		1·45			
FBG (mmol/l)							335·44	<0·001
Mean	5·89		5·48		5·21			
SD	1·80		1·24		1·09			
MetS	1134	26·6	728	21·0	1631	22·5	38·69	<0·001
MetS components								
1	1151	27·0	1138	32·8	2475	34·1	192·38	<0·001
2	1463	34·3	1045	30·1	2462	34·0		
3	823	19·3	572	16·5	1180	16·3		
4	286	6·7	139	4·0	390	5·4		
5	25	0·6	17	0·5	61	0·8		
ASCVD risk								
<5 %	1803	42·3	2192	63·2	4839	66·7	725·33	<0·001
5–10 %	1467	34·4	654	18·9	1438	19·8		
≥10	995	23·2	621	17·9	973	13·4		

SES, social economic status; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; FBG, fasting blood glucose; MetS, metabolic syndrome; ASCVD, atherosclerotic CVD.

Table 2. Factor loadings of food groups in dietary patterns (DP) identified using reduced rank regression (RRR) and principal component analysis (PCA)*

	Urumqi (*n* 4265)			Huo Cheng (*n* 3467)			Mo Yu (*n* 7250)		
Food groups	RRR	PCA1	PCA2	RRR	PCA1	PCA2	RRR	PCA1	PCA2
Rice	−0·19	–	–	–		–	−0·26	–	–
Pasta	–	–	–	–		0·51	–	–	0·13
Grains	−0·22	0·30	0·25	0·20	–	−0·42	0·27	–	–
Pork	−0·20	−0·15	–	−0·15	–	−0·23	–	–	–
Lamb	–	0·14	0·21	0·49	−0·49	0·28	−0·18	–	0·11
Beef	0·13	0·14	–	−0·28	0·65	–	−0·14	–	0·11
Poultry	−0·17	0·13	0·15	–	0·16	0·18	–	0·14	−0·17
Seafood	−0·24	0·23	0·11	−0·17	0·19	–	−0·11	0·11	–
Eggs	−0·24	0·17	0·55	0·12	–	–	0·11	–	0·63
Animal innards	–	–	−0·25	0·16	–	–	−0·10	–	–
Vegetables	–	–	–	−0·10	–	0·34	0·15	–	0·17
Fruits	−0·20	0·13	0·13	0·27	−0·14	0·53	–	–	–
Potatoes	–	0·22	0·20	–	–	0·68	−0·13	0·11	0·23
Beans	–	0·17	0·33	–	0·46	–	−0·37	0·29	−0·28
Milk	−0·10	–	0·72	0·21	–	0·19	−0·23	0·14	–
Yogurt	−0·31	0·26	0·65	0·11	0·12	–	–	–	0·12
Other dairy products	–	–	–	0·36	−0·25	0·34	−0·25	0·15	−0·23
Shortening tea	0·14	–	–	–	–	–	–	–	–
Milk tea	0·30	–	0·13	0·33	−0·35	0·35	−0·14	–	–
Pickles	–	0·11	–	−0·14	0·69	–	−0·20	0·14	–
Dried vegetables	−0·21	0·40	0·20	–	0·69	0·17	–	−0·15	0·34
Nuts	−0·26	0·77	0·15	0·23	–	0·18	0·24	−0·14	0·74
Red dates	−0·26	0·81	0·17	0·11	–	–	0·25	0·14	0·58
Gouji berries	−0·29	0·81	0·13	–	0·21	–	−0·34	0·66	–
Raisins	−0·25	0·84	–	0·12	–	–	–	–	0·66
Dried apricots	−0·25	0·77	–	0·14	–	–	−0·27	0·66	0·20
Soyabean milk	−0·21	0·21	0·46	–	0·11	–	−0·19	0·69	–
Pure fruit juice	–	0·18	0·22	–	0·18	0·11	−0·22	0·80	–
Carbonated drinks	–	–	–	0·12	–	–	−0·13	0·31	–
Other drinks	–	–	–	–	–	–	–	–	0·16

*Loadings lower than |0·1| were deleted for simplicity.

researchers across the globe to investigate the link between the MetS and diet as a modifiable factor. This survey was conducted in typical multi-ethnic rural areas in China, where the main ethnic groups include Han, Uyghur, Kazakh and Hui. They have special genetic characteristics and lifestyle which are quite different from either the Hans in inland provinces of China or American/European populations[30]. In our study, we found large differences in the eating habits of participants between the three survey sites. Potential influencing factors of the MetS include accelerated urbanisation and economic growth. As the representative city with the fastest economic development in Xinjiang, Urumqi has a higher MetS prevalence and 10-year ASCVD risk than the other two survey sites. This is similar to the previous comparative analysis of MetS prevalence among urban and suburban populations in Beijing[31]. In this study, as the components of the MetS increase, the high-risk ASCVD rate increases. In a relatively large-scale prospective cohort study among the Korean population, an association between MetS, insulin resistance and CVD was found. The MetS was associated with risk of CVD, independent of insulin resistance for 10 years of follow-up. Also, the hazard ratio for CVD increased with increasing number of MetS components[32].

We identified and compared DP using two analysis methods. Using PCA, we derived two DP which characterised the dietary habits of the study population. In Urumqi, the first DP was characterised by high intake of rice, beef, vegetables, nuts, red dates and gouji berries; the second one consisted of high intake of milk, yogurt, eggs and soyabean milk. Food composition of these DP partially overlapped with this ‘traditional healthy’ DP examined by the previous study in Xinjiang[33]. The major contributors to the first PCA pattern in Huo Cheng were beef, beans, pickles, dried vegetables and lamb. The second DP was characterised by high positive loadings of pasta, fruit, potatoes, milk tea, as well as by a negative loading of whole grains. Similar DP to those obtained in this study were also identified among Kazakh adults. The DP of the Kazakh are divided into four types: wheat, rice and dairy (36 %); vegetable, dairy and livestock (31·4 %); wheat and dairy (25·3 %); and wheat-cereal (7·3 %)[34]; based on a cross-sectional study of the diet of adult Uyghur residents in Ka shi, four main DP of the population in this area were determined. It includes the DP of grain and vegetables; fruits and milk; meat and eggs; dried fruits and nuts[35]. Consistent with results from the Ka shi population, the first Mo Yu DP in this study was characterised by high intake of pasta, lamb, animal innards and pure fruit juice; the second one consisted of high intake of eggs, nuts, red dates and raisins.

In Urumqi, the RRR-derived DP was characterised by greater intake of milk tea and by lower intake of yogurt, gouji berries, red dates, dried vegetables, nuts, eggs, fishes, seafood, whole grains and soya milk. The Huo Cheng RRR-derived DP was characterised by positive loadings of lamb, milk products, milk tea, fruits and nuts and by negative loadings of beef and fishes/seafood. The RRR-derived DP for Mo Yu was characterised by positive loadings

Table 3. Observing metabolic syndrome by quartiles (Q) and per 1 SD of the dietary pattern (DP) score
(Odds ratios and 95 % confidence intervals)

	Urumqi (*n* 4265)				Huo Cheng (*n* 3467)				Mo Yu (*n* 7250)			
	Crude model		Adjusted model*		Crude model		Adjusted model†		Crude model		Adjusted model‡	
Food groups	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
RRR												
Q1	1		1		1		1		1		1	
Q2	1·33	1·09, 1·63	1·30	1·05, 1·60	0·79	0·64, 0·99	0·87	0·69, 1·11	1·13	0·97, 1·32	1·09	0·93, 1·28
Q3	1·48	1·22, 1·81	1·39	1·13, 1·71	0·73	0·58, 0·91	0·99	0·75, 1·30	1·13	0·97, 1·32	1·09	0·92, 1·29
Q4	1·83	1·51, 2·23	1·57	1·26, 1·95	0·58	0·05, 0·73	0·89	0·61, 1·28	1·17	1·00, 1·37	1·23	1·03, 1·48
P_{trend}	<0·001		<0·001		<0·001		0·663		0·069		0·040	
DP (per 1 SD increase)	1·24	1·16, 1·33	1·17	1·08, 1·27	0·81	0·74, 0·88	0·93	0·81, 1·07	1·08	1·03, 1·14	1·11	1·04, 1·19
PCA1												
Q1	1		1		1		1		1		1	
Q2	1·00	0·83, 1·21	0·94	0·77, 1·14	0·99	0·78, 1·26	0·87	0·68, 1·12	1·19	1·02, 1·39	1·15	0·99, 1·35
Q3	0·96	0·79, 1·16	0·92	0·76, 1·12	1·17	0·92, 1·47	0·93	0·71, 1·21	1·11	0·95, 1·30	1·13	0·96, 1·32
Q4	0·85	0·70, 1·03	0·80	0·65, 0·97	1·23	0·98, 1·56	1·00	0·76, 1·34	1·07	0·91, 1·25	1·12	0·95, 1·31
P_{trend}	0·305		0·157		0·161		0·612		0·180		0·290	
DP (per 1 SD increase)	0·94	0·88, 1·00	0·93	0·86, 0·99	1·08	0·99, 1·17	0·99	0·90, 1·10	1·01	0·96, 1·07	1·04	0·98, 1·09
PCA2												
Q1	1		1		1		1		1		1	
Q2	1·04	0·86, 1·25	1·04	0·86, 1·26	1·20	0·91, 1·58	1·15	0·86, 1·52	1·03	0·88, 1·20	1·04	0·90, 1·22
Q3	0·93	0·75, 1·16	0·92	0·74, 1·15	1·06	0·84, 1·34	1·13	0·88, 1·44	1·05	0·89, 1·25	1·05	0·88, 1·25
Q4	1·01	0·84, 1·21	1·01	0·82, 1·22	0·90	0·72, 1·13	1·10	0·86, 1·40	0·97	0·85, 1·11	0·98	0·86, 1·13
P_{trend}	0·806		0·720		0·124		0·750		0·810		0·834	
DP (per 1 SD increase)	0·99	0·93, 1·06	0·99	0·92, 1·06	0·93	0·85, 1·00	0·99	0·91, 1·08	0·99	0·94, 1·05	0·99	0·94, 1·05

RRR, reduced rank regression; PCA, principal component analysis; SES, social economic status.
*Urumqi adjusted model: adjusted for age, sex, race (han, other), very lower SES (no, yes), current smoking status (no, yes), alcohol drinking status (never, occasional, habitual), physical exercise (never, occasional, habitual) and living area.
† Huo Cheng adjusted model: adjusted for age, sex, race (Han, Uyghur, Hui, Kazakh), very lower SES (no, yes), current smoking status (no, yes), alcohol drinking status (never, occasional, habitual), physical exercise (never, occasional, habitual) and living area.
‡ Mo Yu adjusted model: adjusted for age, sex, very lower SES (no, yes), current smoking status (no, yes), alcohol drinking status (never, occasional, habitual), physical exercise (no, yes) and living area.

of whole grains and red dates and by negative loadings of beans, gouji berries, nuts, rice, milk and milk product and pure juice.

Obviously, the DP extracted by the two methods in this study are different. We found that even though the explained biomarker variation was low, RRR-derived DP were more strongly associated with diseases than PCA-derived patterns. PCA does not necessarily explain the variation and amount of nutrient intake in the identified patterns, rather it explains the cultural and behavioural aspects of food[36]. In line with this, our results showed that although PCA explains the highest variation in food groups, only the first DP derived from PCA in Urumqi was significantly associated with the MetS and ASCVD.

Although the DP derived from a RRR depend on the biomarkers and data included, the food groups that characterised the DP identified in this study have also been reported previously to exert protective effects against the MetS and ASCVD. For example, some scholars derived DP using the RRR method with the MetS as the intermediate variables and found a DP characterised by several foods including those with high glycaemic indices, high-fat meats, cheeses and processed foods and negatively correlated with intakes of vegetables, soya, fruit, green and black tea, low-fat dairy desserts, seeds, nuts and fish[37]. A recent study using data from the China Health and Nutrition Survey reported that the primary RRR dietary score was positively correlated with intakes of wheat or its products, but negatively correlated with low intakes of rice or its products, dark vegetables and animal oil for both sexes[38].

Results of this study support the current dietary guidelines (Dietary Guidelines for Chinese, DGC-2016), suggesting, for example, increasing the consumption of dairy and nuts[39]. A cross-sectional study, conducted among 130 420 subjects, concluded that higher milk consumption was associated with the lower odds of the MetS in Korean adults[40]. Prospective cohort studies consistently suggest that yogurt consumption may contribute to a reduction in adiposity indexes, the risk of the MetS and diet-related cardiometabolic diseases[41–42]. Our study in Urumqi showed that yogurt had the highest impact on the metabolic profile-associated DP. However, it may be due to the shortage of cow resources, which leads to the low consumption of milk and dairy products in Mo Yu. Besides yogurt, milk tea is the second popular dairy product in Xinjiang. So, it is worth noting the relationship between milk tea and the risk of MetS and predicted ASCVD. Hydrogenated vegetable oils used in the processing of dairy products such as milk tea also contain a large amount of *trans*-fatty acids[43]. The high intake of *trans*-fatty acids promotes arteriosclerosis and causes type 2 diabetes and heart disease[44].

Epidemiologists found a negative correlation between the frequency of nut consumption and the incidence of the MetS[45], and the beneficial effects of nuts on cardiovascular health are attributed to their abundance of a variety of bioactive compounds. Another study has shown that people with higher whole-grain intake have a 29 % lower ASCVD risk than those with lower whole-grain intake[46]. However, the opposite result

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Table 4. Predicting 10-year atherosclerotic CVD risk by quartiles (Q) and per 1 SD of the dietary pattern (DP) score
(Odds ratios and 95 % confidence intervals)

	Urumqi (*n* 4265)				Huo Cheng (*n* 3467)				Mo Yu (*n* 7250)			
	Crude model		Adjusted model*		Crude model		Adjusted model†		Crude model		Adjusted model‡	
	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
RRR												
Q1	1		1		1		1		1		1	
Q2	1·58	1·33, 1·87	1·53	1·14, 2·05	0·92	0·75, 1·13	0·99	0·74, 1·33	1·11	0·96, 1·29	1·17	0·93, 1·46
Q3	2·44	2·05, 2·90	2·22	1·64, 3·00	0·68	0·55, 0·84	0·92	0·65, 1·30	1·54	1·34, 1·78	1·34	1·07, 1·68
Q4	3·46	2·89, 4·14	1·55	1·13, 2·13	0·50	0·40, 0·62	0·79	0·50, 1·23	2·43	2·11, 2·80	1·63	1·27, 2·08
P_{trend}	<0·001		0·005		<0·001		0·340		<0·001		<0·001	
DP (per 1 SD increase)	1·69	1·58, 1·81	1·30	1·15, 1·47	0·74	0·69, 0·80	0·87	0·73, 1·03	1·41	1·34, 1·49	1·25	1·14, 1·36
PCA1												
Q1	1		1		1		1		1		1	
Q2	1·23	1·03, 1·46	0·71	0·53, 0·96	1·28	1·06, 1·56	1·17	0·87, 1·58	1·22	1·06, 1·39	0·91	0·74, 1·13
Q3	0·99	0·83, 1·17	0·77	0·57, 1·03	1·38	1·13, 1·67	1·30	0·95, 1·79	0·89	0·78, 1·03	1·05	0·85, 1·29
Q4	0·83	0·70, 0·98	0·57	0·42, 0·76	1·07	0·88, 1·31	0·95	0·68, 1·34	0·70	0·61, 0·81	1·02	0·82, 1·27
P_{trend}	<0·001		0·003		0·004		0·116		<0·001		0·605	
DP (per 1 SD increase)	0·92	0·86, 0·97	0·83	0·75, 0·93	1·06	0·99, 1·14	1·03	0·92, 1·17	0·86	0·83, 0·91	1·02	0·95, 1·10
PCA2												
Q1	1		1		1		1		1		1	
Q2	1·10	0·93, 1·30	1·32	1·00, 1·7	1·03	0·82, 1·30	0·87	0·62, 1·23	0·09	0·78, 1·02	0·85	0·69, 1·05
Q3	0·93	0·77, 1·13	0·85	0·62, 1·16	0·79	0·64, 0·96	0·80	0·60, 1·07	0·96	0·82, 1·12	0·87	0·69, 1·10
Q4	0·87	0·74, 1·02	0·77	0·59, 1·03	0·68	0·57, 0·82	0·94	0·71, 1·25	0·76	0·67, 0·85	0·88	0·73, 1·06
P_{trend}	0·031		0·002		<0·001		0·454		<0·001		0·360	
DP (per 1 SD increase)	0·93	0·88, 0·99	0·87	0·79, 0·97	0·86	0·81, 0·92	0·97	0·88, 1·08	0·90	0·86, 0·94	0·95	0·88, 1·03

RRR, reduced rank regression; PCA, principal component analysis; SES, social economic status.
*Urumqi adjusted model: adjusted for age, sex, race (han, other), very lower SES (no, yes), current smoking status (no, yes), alcohol drinking status (never, occasional, habitual), physical exercise (never, occasional, habitual) and living area.
† Huo Cheng adjusted model: adjusted for age, sex, race (Han, Uyghur, Hui, Kazakh), very lower SES (no, yes), current smoking (no, yes), alcohol drinking (never, occasional, habitual), physical exercise (never, occasional, habitual) and living area.
‡ Mo Yu adjusted model: adjusted for age, sex, very lower SES (no, yes), current smoking (no, yes), alcohol drinking (never, occasional, habitual), physical exercise (no, yes) and living area.

was found between whole grains and the risk of the MetS and elevated ASCVD in Mo Yu. Mo Yu is one of the poorest areas in Xinjiang, and people have low SES. Increasing whole-grain cereals only may not influence adiponectin levels, but levels could be modified by a fibre-rich, low-fat, low-glycaemic index diet, possibly through changes in gut microbiota[47]. A study examined anthropometric and biochemical parameters in patients with the MetS after the consumption of gouji berries, and results suggested that it is an effective dietary supplement for the prevention of CVD in individuals with the MetS[48]. Our results are also in agreement with a study that found that lower consumption of gouji berries and eggs may increase the risk of the MetS and elevated ASCVD[49]. Studies on the relationship between eggs intake and the MetS and ASCVD are inconsistent. A previous study has suggested that incorporating daily eggs intake into a moderately carbohydrate-restricted diet provides further improvements in the atherogenic lipoprotein profile and in insulin resistance in individuals with the MetS[50].

Strengths and limitations

To the best of our knowledge, this study is the first to investigate potential relationships between overall diet and metabolic profiles in Xinjiang. We are aware that the RRR method is limited to existing studies with biomarkers or intermediate variables and knowledge of the diet–disease association. Nevertheless, this innovative method has the advantage of investigating the pathway between diet and disease, as opposed to exploratory factor analysis and cluster analysis which are entirely data driven. The strength of our study included the large sample size and the fact that we included three survey sites with different geographical, cultural and socio-economic characteristics. We focused on central obesity rather than BMI. The reasons are as follows. First, according to the International Diabetes Federation criteria definition, central obesity is the first step to defining the MetS, followed by the other International Diabetes Federation criteria factors. Additionally, it was associated with insulin resistance and contributed to the MetS and its components. Moreover, significant evidence linked larger WC with the development of CVD[51]. Most importantly, the prevalence of adult central obesity in Xinjiang is significantly higher than that in other regions[17].

We acknowledge that our study has some limitations. First, we acknowledge that the retrospective FFQ bears the risk of under- or over-reporting of food items in the dietary assessments. The administration of a locally specific FFQ, by trained nurses of the same cultural background and language helped to keep this information bias to a minimum. Second, our cross-sectional analyses may be affected by reverse causation due to changes in dietary behaviour as a result of developing MetS. Third, residual confounding, particularly from physical activities that are hard to measure precisely with a self-report questionnaire and that are closely related to both the MetS and diet in terms of energy intake and type of DP. Furthermore, since the FFQ used in our study only investigated food group intake without reporting single foods, it is impossible to accurately calculate the individual's daily energy intake. Finally, because information regarding hyperlipidaemia medication was not available, HDL-cholesterol and TAG were not adjusted in those participants taking lipid-lowering medication. Further studies are needed to explore the association of DP with the MetS and ASCVD 10-year risk using a longitudinal study.

Conclusion

We derived DP that reflected metabolic profiles using RRR and PCA. These DP were associated with higher risk of the MetS and elevated 10-year ASCVD risk in Chinese adults. Our findings suggest that using metabolic profile biomarkers as response variables in RRR may be a promising approach to identify DP related to chronic disease risk. Furthermore, our findings may help clinicians and dietitians develop dietary strategies for preventing the MetS and ASCVD.

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G. H., D. L.-W. and J. H.-D. designed the research; Y. M., G. H., Z. C., T. T., T. L. and D. A. contributed to the analysis and interpretation of data for the work; G. H., W. H.-F., H. L.-P., L. W., G. Z.-Z. and L. R.-L. wrote the paper; T. L. and J. H.-D. contributed to acquisition of the data; and all authors provided input and approved the final manuscript.

None of the authors has any conflicts of interest to declare.

Supplementary material

For supplementary materials referred to in this article, please visit https://doi.org/10.1017/S000711452000478X

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