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The association between nutrient patterns and metabolic syndrome among Iranian adults: cross-sectional analysis of Shahedieh cohort study

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Abstract
Objective: To assess the association between patterns of nutrient intake and metabolic syndrome (MetS) in a large sample of Iranian adults.
Design: Baseline data from the Shahedieh cohort study were used in the current cross-sectional study. Dietary intakes were assessed through the use of a validated semi-quantitative FFQ. Nutrient patterns (NP) were derived using factor analysis. The MetS was defined according to criteria introduced from the National Cholesterol Education Program Adult Treatment Panel III, modified for Iranian adults.
Setting: Yazd, Iran.
Participants: A total of 7325 Iranian adults aged between 30 and 75 years.
Results: Three NP were identified. A significant positive association was found between adherence to semi-plant NP (characterised by the high intakes of P; vitamins B_1, B_3, B_6 and B_5; Se; Mg; Fe; protein; Cr; Cu; fibre; biotin; Mn; Zn and Na) and odds of MetS (OR 1·68, 95 % CI 1·43, 1·98). However, after adjusting for potential confounders, this association became non-significant. In addition, after taking potential confounders into account, individuals in the highest quintile of the semi-animal NP, rich in Ca; K; vitamins B_2, B_{12}, A, D, K and C; SFA; dietary cholesterol and *trans*-fatty acid, were 26 % more likely to have MetS compared with those in the lowest quintile (OR 1·26, 95 % CI 1·05, 1·51). No significant association was seen between adherence to the high-carbohydrate/low-fat NP and odds of MetS.
Conclusions: We found that adherence to a semi-animal NP was associated with increased odds of MetS.

Keywords
Nutrient pattern
Metabolic syndrome
Nutrition epidemiology
Abdominal obesity

Metabolic syndrome (MetS) is a complex metabolic disorder that is associated with an increased risk of CVD, stroke and mortality[1–3]. This syndrome imposes a large burden and cost to healthcare system[4]. The prevalence of MetS has been increasing at an alarming rate. In the USA, 40 % of adults are affected by this syndrome[5]. National estimates in Iran showed a prevalence of 30 % among Iranian adults[6]. Therefore, finding the appropriate strategies to prevent MetS is of great importance.

A complicated combination between genetic, metabolic and environmental factors, including diet, contributes to the aetiology of MetS and its components[7–12]. Prior studies reported that lower intakes of hydrogenated vegetable oil, refined grains and red meat, and greater intakes of vegetables, antioxidants and Ca are associated with decreased odds of MetS[13–18]. Traditionally, published studies have mainly focused on individual nutrients, foods and food groups, and little attention has been laid on the

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patterns of dietary intakes, particularly patterns of nutrient intake[19,20]. As we know, people do not consume nutrients separately and in fact, they consume several nutrients together, which might interact with each other[21]. Nutrients can synergistically affect the absorption and function of the others. Furthermore, considering the patterns of nutrient intake has several priorities compared with dietary patterns. Nutrients are consumed by people worldwide, while the consumption of foods is dependent on geographical region and culture[22]. Therefore, nutrient pattern (NP) analysis provides a more realistic view of diet–disease relationships than dietary pattern analysis, particularly when comparing dietary intakes across different nations. In addition, compared with foods, nutrients functionally cannot be exchanged. In NP analysis, unlike food patterns, the underlying mechanisms on the diet–disease associations can be explained by nutrient content of patterns. Also, NP analysis can be an interface between food patterns and food metabolome integrating the measurements of both diet and metabolism[22–24].

Based on our literature search, we only found two studies examining the association between patterns of nutrient intake and MetS[25,26]. In the study of Bian *et al.*[25], 'B-vitamins' pattern was inversely associated with MetS in Chinese adults, while in another cross-sectional study, adherence to a pattern rich in riboflavin and vitamin B_{12} was positively associated with MetS[26]. Therefore, data in this regard are conflicting. In addition, few studies are available from the understudied region of the Middle East, where the prevalence of MetS is estimated to be high[6,27]. In this region, a specific type of abdominal obesity, which is characterised by abdominal fat accumulation and enlarged waist circumference, is prevalent, particularly among women[28,29]. This type of abdominal obesity might be a reason for the high prevalence of hyperlipidaemia among Middle Eastern women. Therefore, assessing the contributing factors to MetS is important in this region. Hence, the current study aimed to assess the relationship between patterns of nutrient intake and MetS among a large sample of Iranian adults.

Materials and methods

Participants and study design

The current study was a cross-sectional analysis of the Shahedieh cohort study which was a part of the PERSIAN (Prospective Epidemiological Research Studies in Iran) cohort study that is carrying out in different cities of Iran. The purpose of the PERSIAN cohort was to identify the potential risk factors of non-communicable diseases. This cohort was done by investigators at local universities in cooperation with the Ministry of Health and Medical Education. Detailed information about the study design, participants and data collection methods of the PERSIAN cohort has been published previously[30]. In brief, the Shahedieh cohort study was started in the Shahedieh region of Yazd city, Iran, in 2014. At baseline, all adults (n 10 194) with an age range of 35–70 years from this region were invited to participate in this cohort. Inclusion criteria were being of Iranian descent and living in the Shahedieh region for at least 9 months of the year. However, we excluded individuals with physical or psychological disabilities that render them unable to complete the enrolment process. In order to collect data, participants were invited to the health centre of Shahedieh. They were asked to arrive in a fasting state for the collection of biological samples. Among 10 194 adults who were invited, 9977 participated in the current study. After taking the blood sample from each participant, required information about socio-demographic characteristics, physical activity and dietary intakes was gathered by trained interviewers. After merging data and excluding participants with incomplete data on exposure and outcome variables as well as those who had under- and over-reporting for energetic intake according to the ±3 SD of mean energy intake, 7325 remained for the final analysis. No significant difference was seen in terms of demographical variables between individuals included and excluded from the analysis. All participants provided written informed consent.

Dietary assessment

We used a validated block-format 120-item semi-quantitative FFQ which was online for gathering data on dietary intakes. This questionnaire was specifically designed for Iranian adults. Details on the design, foods included as well as the validity of this questionnaire were published previously[31]. Trained interviewers recorded dietary intake of each food item in three steps based on participants' responses. In the first step, interviewer recorded the frequency of consumption for each food item and then the amount of consumption at any time was recorded (step 2). In the third step, the number of months that seasonal foods were consumed during the past year was recorded. To determine the amount of consumption, interviewers showed household measures to individuals for increasing the accuracy of estimations. Finally, based on the consumption frequency and amount of consumption at each time as well as the number of months that each food was consumed in the past year, we calculated the intake of each food item as g/d. In addition, we calculated the daily nutrients intake for each participant according to the nutrient contents of all foods. The US Department of Agriculture's national nutrient databank was used to obtain nutrient contents of foods[32]. Findings from previous studies revealed that the FFQ could provide reasonably valid and reliable measures of long-term dietary intakes in the Iranian population[17,31].

Biochemical assessment

Twenty-five millilitres of blood was collected from each individual in a fasting state using Vacutainers (Greiner Bio-One

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International GmbH). Then, blood was centrifuged and fractioned into different aliquots which were labelled and stored in freezers (–70°C). In addition to storing the samples, a small amount of blood was used to measure fasting blood glucose, TAG and HDL-cholesterol concentrations. We used an enzymatic colorimetric method to measure fasting blood glucose. TAG levels were measured via enzymatic colorimetric tests with glycerol phosphate. To measure HDL-cholesterol concentrations, the precipitation of the apoB-containing lipoproteins with phosphotungstic acid was determined. We applied commercially available enzymatic reagents (Pars Azmoon), adopted to an auto-analyzer system (Selectra E; Vitalab) for all measurements.

Anthropometric measures

All anthropometric indicators were measured according to the US National Institutes of Health protocols. Weight was measured using a digital scale at the state of minimum clothing without shoes to the nearest 100 g. Standing height was measured using a standard stadiometer, without shoes, to the nearest 0·5 cm. BMI was calculated as weight (kg)/height (m^2). Waist circumference was measured using a strip metre at mid-distance interval between the super elliptic bone and the last gear, to the nearest 0·5 cm. To reduce measurement error/bias to the lowest levels, anthropometric data were acquired in the morning and after sample collection, while the participant was still fasting.

Assessment of other variables

To measure blood pressure, first, subjects were asked to rest for 10 min. Then, blood pressure was measured by the use of a standard mercury sphygmomanometer at the right arm, three times with a 5-min interval, when subjects were sitting. Subjects' blood pressure was considered as the average of three measurements. We used the International Physical Activity Questionnaire to measure the physical activity of participants through face-to-face interviews. All results of the International Physical Activity Questionnaire were expressed as metabolic equivalents per week (MET-h/week). International Physical Activity Questionnaire was translated to Farsi and validated for the Iranian population previously[33]. Further information on age, gender (male/female), education (university graduated/non-university education), marital status (married/single/divorced), house possession (owner/non-owner), smoking (non-smoker/ex-smoker/current smoker), family size (≥4/<4 people), supplement use (yes/no), having frequent night work shift (≥1 shift per month) and history of depression and thyroid disorders was collected using pretested questionnaires via face-to-face interview.

Definition of terms

We defined the MetS according to the National Cholesterol Education Program Adult Treatment Panel III, modified for Iranian adults[34]. The presence of at least three components of the following abnormalities was considered as MetS: (i) abnormal glucose homoeostasis (fasting blood glucose of ≥5·55 mmol/l), (ii) low concentrations of HDL-cholesterol (<1·28 mmol/l for women and <1·02 mmol/l for men), (iii) high serum TAG (≥1·69 mmol/l), (iv) elevated blood pressure (systolic blood pressure ≥130 mmHg and diastolic blood pressure ≥85 mmHg) and (v) abdominal obesity (waist circumference ≥ 95 cm for both genders). Iranian National Committee of Obesity proposed a single cut-point of waist circumference ≥ 95 cm to define abdominal obesity for Iranian men and women[35].

Statistical analysis

First, we obtained energy-adjusted intakes of thirty-four nutrients and bioactive compounds by the residual method[21] and then factor analysis with the orthogonal transformation (varimax procedure) was applied to determine major NP. To examine if the distribution of the different nutrients allows the use of principal components, the Kaiser–Meyer–Olkin test was used. Obtained factors were retained for further analysis based on Eigen values on the Scree plot. In the current study, we retained factors with Eigen values of ≥2·5 to extract major NP.

In the current study, participants were categorized based on quintiles of NP' scores. Differences in quantitative variables across quintiles of NP' scores were determined using one-way ANOVA. To assess the distribution of categorical variables across quintiles of NP' scores, the χ^2 test was used. We applied the binary logistic regression in different models to determine OR and 95 % CI for MetS across quintiles of NP' scores. In the first model, we adjusted for age, gender and energy intake. Further adjustment was made for education (university graduated/non-university education), marital status (married/single/divorced), house possession (owner/non-owner), family size (≥4/<4 people), smoking (none or ex-smoker/current smoker), supplement use (yes/no), having frequent night work shift (≥1 shift per month), physical activity (continuous) and history of depression and thyroid disorders in the second model. BMI was additionally adjusted in the final model to see if the association is independent of obesity. In all models, participants in the first quintile of NP' scores were considered as the reference group. To obtain the trend of OR across increasing quintiles of NP' scores, we considered these categories as an ordinal variable. The statistical analyses were conducted using SPSS version 20. *P* values were considered significant at <0·05.

Results

Mean age of study participants was 48·51 ± 9·69 years, and 54·9 % were female. The MetS was prevalent among 26·1 % of individuals participated in the current study.

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Table 1 Factor-loading matrix of nutrients used in the nutrient pattern (NP) analysis

	Semi-plant NP	Semi-animal NP	High-carbohydrate/ low-fat NP
P	0·919		
Vitamin B_1	0·840	−0·392	0·206
Se	0·830	−0·466	0·208
Vitamin B_3	0·823	−0·386	
Mg	0·823	−0·312	0·242
Fe	0·822	−0·465	0·208
Protein	0·812	0·335	
Cr	0·788	−0·506	0·249
Cu	0·775	−0·279	
Total fibre	0·772	−0·331	0·350
Biotin	0·753		0·287
Mn	0·730	−0·534	0·309
Vitamin B_6	0·725	0·335	
Zn	0·700		
Vitamin B_5	0·631	0·587	
Na	0·424	−0·300	
Fluoride	−0·362		0·256
Folate	0·263		
Ca	0·217	0·784	
K		0·739	
Vitamin B_{12}		0·704	−0·230
Vitamin B_2	0·553	0·666	
Vitamin A		0·663	
SFA	−0·297	0·613	−0·510
Cholesterol		0·576	−0·278
Vitamin C	−0·265	0·556	
Vitamin D		0·503	
Vitamin K		0·359	
Trans-fatty acids		0·208	
MUFA	−0·256		−0·846
Carbohydrate	0·213	−0·415	0·842
PUFA	−0·313		−0·781
Refined sugar			0·747
Vitamin E	−0·203		−0·657

Factor loadings <0·20 are not shown for simplicity.

Based on factor analysis, we identified three NP (Table 1). The Kaiser–Meyer–Olkin value was 0·77 indicating good sampling adequacy. The first nutrient pattern (NP1) was rich in P; vitamins B_1, B_3, B_6 and B_5; Se; Mg; Fe; protein; Cr; Cu; dietary fibre; biotin; Mn; Zn and Na. The second one (NP2) was greatly loaded with Ca; K; vitamins B_2, B_{12}, A, D, K and C; SFA; dietary cholesterol and *trans*-fatty acid (TFA). The third nutrient pattern (NP3) was characterised by the high consumption of carbohydrate and refined sugar, and lower intakes of vitamin E, PUFA, MUFA and SFA. Overall, these NP explained 62·4 % of the variance.

General characteristics of participants across quintiles of NP' scores are indicated in Table 2. Compared with participants in the bottom quintile of NP1, those in the top quintile were more likely to be female, house owner, have thyroid disorders, abnormal glucose homoeostasis, abdominal obesity and MetS, and less likely to be of large family sizes, current smoker, university educated and have frequent night work shift. In addition, greater adherence to NP1 was associated with higher age, BMI, fasting blood glucose, HDL-cholesterol and lower physical activity. Within the NP2, individuals in the highest quintile were more likely to be male, physically active, married, current smoker, university graduated, have frequent night work shift and elevated concentrations of serum TAG, and less likely to have depression, thyroid disorders, low serum HDL-cholesterol concentrations and abdominal obesity compared with those in the lowest quintile. In terms of NP3, participants in the fifth quintile were more likely to be older, female, house owner, current smoker, have abnormal glucose homoeostasis, abdominal obesity and MetS, and less likely to be married, university graduated, of large family sizes and to have frequent night work shift compared with those in the first quintile.

Dietary intakes of participants across quintiles of NP' scores are shown in Table 3. Greater adherence to the NP1 was associated with higher intake energy, protein, carbohydrate, vitamin B_6, folate, Fe, Ca, Na, dietary fibre and refined grains, and lower intake of fat, SFA, vitamin E, vitamin C, vegetables, dairy, fruits, whole grains, legumes, nuts and red meat. Within the NP2, participants in the top quintile had greater intake of fat; protein; SFA; vitamins B_6 and C; Ca; vegetables; dairy; fruits; whole grains; legumes; nuts and red meat, and lower intake of energy, carbohydrate, vitamin E, folate, Fe, Na, dietary fibre and refined grains than those in the bottom quintile. Greater adherence to NP3 was associated with higher intake of energy, carbohydrate, vitamin B_6, folate, vitamin C, Fe, dietary fibre, vegetables, fruits and refined grains, and lower intake of protein, fat, SFA, vitamin E, Ca, Na, dairy, whole grains, legumes, nuts and red meat.

Multivariable-adjusted OR and 95 % CI for MetS across quintiles of NP' scores are shown in Table 4. A significant positive association was found between adherence to the NP1 and MetS (OR 1·68, 95 % CI 1·43, 1·98). This association was significant even after controlling for age, gender and energy intake (OR 1·22, 95 % CI 1·03, 1·45). However, after adjusting for socio-demographic variables and BMI, this association became non-significant. In terms of NP2, no significant association was seen with MetS. However, after taking potential confounders into account, individuals in the highest quintile of NP2 were 26 % more likely to have MetS compared with those in the lowest quintile (OR 1·26, 95 % CI 1·05, 1·51). Moreover, a significant positive association was found between adherence to NP3 and odds of MetS (OR 1·41, 95 % CI 1·19, 1·66); however, in the fully adjusted model, this association became non-significant.

Discussion

In the current study, we found that adherence to NP2 was positively associated with MetS. NP2 was rich in Ca; K; vitamins B_2, B_{12}, A, D, K and C; SFA; dietary cholesterol and TFA. This association was obtained after taking potential confounders into account. However, in the fully adjusted model, no significant association was seen between adherence to NP1 and NP3 and MetS.

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Table 2 General characteristics of participants across quintiles of nutrient patterns' (NP) scores

	Semi-plant NP							Semi-animal NP							High-carbohydrate/low-fat NP						
	Q1		Q3		Q5			Q1		Q3		Q5			Q1		Q3		Q5		
	Mean	SE	Mean	SE	Mean	SE	P*	Mean	SE	Mean	SE	Mean	SE	P*	Mean	SE	Mean	SE	Mean	SE	P*
n	1465		1465		1465			1465		1465		1465			1465		1465		1465		
Age (years)	46·0	0·2	48·0	0·2	51·7	0·2	<0·001	48·4	0·2	48·0	0·2	48·7	0·2	0·24	44·8	0·2	48·0	0·2	52·7	0·2	<0·001
Female (%)	39·2		58·0		61·0		<0·001	65·7		55·9		39·8		<0·001	51·2		58·2		52·0		<0·001
BMI (kg/m^2)	28·0	0·2	28·5	0·1	28·9	0·1	0·002	28·5	0·1	28·6	0·2	28·3	0·2	0·92	28·4	0·1	28·6	0·1	28·3	0·1	0·61
WC (m)	94·4	0·3	101·4	5·8	97·8	0·3	0·32	95·7	0·3	95·6	0·2	96·0	0·2	0·40	95·1	0·3	95·4	0·3	96·1	0·3	0·36
PA (MET-h/d)	41·9	0·1	40·7	0·1	40·3	0·1	<0·001	40·3	0·1	41·0	0·1	41·6	0·1	<0·001	41·0	0·1	40·6	0·1	41·1	0·1	0·07
FBG (mmol/l)	5·64	0·04	5·82	0·05	6·46	0·07	<0·001	5·76	0·04	5·80	0·06	6·11	0·06	<0·001	5·82	0·05	5·87	0·05	5·97	0·05	0·34
TAG (mmol/l)	1·90	0·03	1·87	0·03	1·83	0·02	0·44	1·80	0·03	1·87	0·03	1·93	0·03	0·004	1·89	0·03	1·82	0·02	1·91	0·03	0·31
HDL-cholesterol (mmol/l)	1·31	0·007	1·35	0·007	1·38	0·007	<0·001	1·37	0·007	1·36	0·01	1·33	0·007	0·06	1·33	0·007	1·36	0·007	1·35	0·007	0·09
Married (%)	96·7		95·2		94·7		0·05	92·4		96·3		97·3		<0·001	95·8		95·7		93·4		<0·001
University graduated (%)	14·5		16·3		12·3		<0·001	10·5		15·8		18·6		<0·001	18·4		15·9		10·9		<0·001
House owner (%)	91·4		95·5		97·7		<0·001	94·1		95·2		95·9		0·13	92·2		95·4		96·0		<0·001
Family size (≥4 people) (%)	67·7		63·9		54·0		<0·001	61·7		61·3		62·7		0·30	67·4		63·2		52·6		<0·001
Current smoker (%)	24·3		10·7		7·2		<0·001	12·6		11·5		15·2		0·006	13·4		10·3		16·3		<0·001
Frequent night work shift (%)	8·5		4·4		4·0		<0·001	4·2		5·5		6·9		0·01	7·8		4·6		3·8		<0·001
Depression (%)	14·5		15·9		16·2		0·63	19·1		14·9		11·1		<0·001	14·9		14·7		17·6		0·05
Thyroid disorders (%)	10·0		13·6		13·0		<0·001	15·7		14·3		10·2		<0·001	12·7		14·0		12·4		0·18
Supplement use (yes) (%)	2·5		3·6		3·3		0·40	3·5		3·3		3·1		0·57	3·5		2·8		2·3		0·05
MetS (%)	22·5		25·4		32·8		<0·001	25·0		25·3		27·4		0·55	22·6		23·1		29·1		<0·001
Abnormal glucose homoeostasis (%)	31·3		36·0		49·5		<0·001	35·7		36·7		42·7		0·001	33·5		37·5		41·2		<0·001
Elevated BP (%)	3·9		5·9		5·5		0·05	5·2		4·9		5·0		0·86	3·5		4·6		6·3		0·01
High serum TAG (%)	46·3		45·9		45·9		0·45	42·6		47·2		49·1		<0·001	46·3		44·0		47·8		0·13
Low serum HDL-cholesterol (%)	23·4		26·8		22·7		0·09	25·9		25·1		19·9		0·001	25·1		22·5		23·7		0·41
Abdominal obesity (%)	49·1		52·2		60·7		<0·001	52·4		53·0		55·5		0·48	49·0		51·4		56·2		<0·001

WC, waist circumference, PA, physical activity, FBG, fasting blood glucose, MetS, metabolic syndrome, BP, blood pressure.
Data are presented as mean and SE or percentages.
*Obtained from one-way ANOVA or χ^2 test, where appropriate.

Table 3 Dietary intakes of participants across quintiles of nutrient patterns' (NP) scores

	Semi-plant NP							Semi-animal NP							High-carbohydrate/low-fat NP						
	Q1		Q3		Q5			Q1		Q3		Q5			Q1		Q3		Q5		
	Mean	SE	Mean	SE	Mean	SE	*P**	Mean	SE	Mean	SE	Mean	SE	*P**	Mean	SE	Mean	SE	Mean	SE	*P**
n	1465		1465		1465			1465		1465		1465			1465		1465		1465		
Nutrients																					
Energy	3679·1	25	2915	28	3951·8	33	<0·001	3678·9	34	3148·9	29	3507	27	<0·001	3470·2	28	3140·9	30	3524·2	32	<0·001
Protein (g/d)	98·4	0·3	116·4	0·1	127·3	0·2	<0·001	109·2	0·4	114·9	0·2	120·9	0·3	<0·001	113·8	0·4	117·1	0·2	110·0	0·3	<0·001
Fat (g/d)	100·4	0·6	90·3	0·3	78·5	0·3	<0·001	83·3	0·5	89·0	0·4	98·5	17·6	<0·001	112·5	0·4	87·0	0·2	74·0	0·3	<0·001
Carbohydrate (g/d)	518·0	1·5	529·5	0·9	551·6	1·0	<0·001	554·6	1·1	534·1	0·9	503·9	1·2	<0·001	476·7	1·1	536·7	0·5	577·1	0·7	<0·001
SFA (g/d)	30·9	0·2	28·2	0·1	24·5	0·1	<0·001	22·7	0·1	27·6	0·1	34·2	0·1	<0·001	33·3	0·2	27·5	0·1	23·6	0·1	<0·001
Vitamin E (mg/d)	20·4	0·2	18·5	0·1	15·9	0·1	<0·001	20·6	0·2	18·1	0·1	17·2	0·1	<0·001	26·2	0·2	16·8	0·1	14·1	0·09	<0·001
Vitamin B_6 (mg/d)	2·1	0·009	2·5	0·004	2·7	0·005	<0·001	2·3	0·008	2·4	0·006	2·6	0·008	<0·001	2·3	0·008	2·5	0·006	2·4	0·009	<0·001
Folate (μg/d)	657·3	3·3	697·4	1·7	709·0	1·6	<0·001	687·6	2·3	692·2	2·1	683·0	2·5	0·01	663·0	2·4	702·0	1·9	692·5	2·7	<0·001
Vitamin C (mg/d)	145·0	2·4	120·8	1·6	85·0	1·5	<0·001	67·2	1·1	111·3	1·2	183·7	2·7	<0·001	114·3	1·6	109·0	1·5	141·2	2·7	<0·001
Fe (mg/d)	22·0	0·1	28·7	0·06	34·2	0·1	<0·001	31·4	0·1	28·9	0·1	24·4	0·1	<0·001	25·5	0·1	29·5	0·1	28·9	0·1	<0·001
Ca (mg/d)	1085·3	8·1	1183·8	6·3	1240·8	8·7	<0·001	927·7	3·7	1142·6	3·8	1527·6	9·2	<0·001	1174·3	8·9	1196·2	7·0	1128·4	7·3	<0·001
Na	4987·5	36	5757·7	26	6562·9	32	<0·001	6285·4	38	5834·0	34	5163·2	32	<0·001	5713·2	40	5892·2	29	5576·3	32	<0·001
Fibre (g/d)	39·1	0·3	55·9	0·1	69·7	0·2	<0·001	60·9	0·4	56·0	0·3	47·8	0·3	<0·001	45·5	0·3	57·5	0·2	59·9	0·4	<0·001
Food groups (g/d)																					
Vegetables	279·6	4·7	264·7	3·8	232·1	4·5	<0·001	159·3	2·5	251·5	2·9	380·6	6·1	<0·001	267·3	4·0	248·9	3·6	280·7	5·7	<0·001
Dairy	325·8	5·5	317·0	4·7	288·6	6·6	<0·001	130·4	2·2	285·6	2·5	576·0	6·7	<0·001	348·6	6·3	314·8	5·2	271·7	5·1	<0·001
Fruits	543·8	10·1	441·8	6·3	301·0	5·6	<0·001	249·0	4·8	420·9	5·7	652·9	10·2	<0·001	381·4	6·0	393·7	6·1	567·4	10·7	<0·001
Whole grains	205·9	4·9	254·6	5·5	197·2	8·4	<0·001	194·4	7·4	246·6	6·0	241·4	5·5	<0·001	241·7	5·8	227·6	6·0	211·6	6·5	<0·001
Refined grains	383·5	7·2	559·5	6·6	784·9	10·4	<0·001	752·8	9·9	572·9	7·1	364·4	6·9	<0·001	445·1	7·6	619·2	7·7	594·8	9·5	<0·001
Legumes	32·9	0·7	31·6	0·6	26·0	0·7	<0·001	24·1	0·5	29·9	0·6	36·2	0·7	<0·001	35·2	0·7	30·1	0·6	27·0	0·6	<0·001
Nuts	27·8	1·0	15·5	0·4	5·8	0·3	<0·001	11·8	0·7	15·8	0·6	20·0	0·7	<0·001	27·9	1·1	13·9	0·4	10·0	0·4	<0·001
Red meat	37·2	0·7	35·2	0·6	26·9	0·8	<0·001	22·8	0·5	34·3	0·6	43·9	0·9	<0·001	44·4	1·0	31·9	0·5	26·0	0·5	<0·001

All values are presented as mean and SE and adjusted for energy except for dietary energy intake.
*Obtained from one-way ANOVA.

Table 4 OR and 95 % CI for the metabolic syndrome across quintiles of nutrient patterns' (NP) scores

	n	Crude		Model 1*		Model 2†		Model 3‡	
		OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Semi-plant NP									
Q1	1465	1·00		1·00		1·00		1·00	
Q2	1465	1·06	0·89, 1·26	1·00	0·84, 1·20	0·99	0·83, 1·19	0·97	0·81, 1·17
Q3	1465	1·18	0·99, 1·39	1·08	0·91, 1·29	1·07	0·89, 1·28	1·03	0·86, 1·25
Q4	1465	1·24	1·05, 1·47	1·06	0·89, 1·27	1·06	0·88, 1·27	1·03	0·85, 1·25
Q5	1465	1·68	1·43, 1·98	1·22	1·03, 1·45	1·20	1·00, 1·44	1·20	0·99, 1·45
P_{trend}		<0·001		0·021		0·036		0·043	
Semi-animal NP									
Q1	1465	1·00		1·00		1·00		1·00	
Q2	1465	1·09	0·92, 1·28	1·16	0·98, 1·38	1·16	0·97, 1·38	1·15	0·96, 1·39
Q3	1465	1·02	0·86, 1·20	1·14	0·96, 1·36	1·16	0·97, 1·38	1·15	0·96, 1·39
Q4	1465	1·07	0·91, 1·26	1·20	1·00, 1·42	1·21	1·01, 1·44	1·17	0·97, 1·41
Q5	1465	1·14	0·96, 1·34	1·26	1·07, 1·51	1·32	1·10, 1·57	1·26	1·05, 1·51
P_{trend}		0·204		0·011		0·003		0·027	
High-carbohydrate/low-fat NP									
Q1	1465	1·00		1·00		1·00		1·00	
Q2	1465	1·23	1·04, 1·46	1·15	0·97, 1·36	1·18	0·99, 1·41	1·18	0·98, 1·42
Q3	1465	1·03	0·87, 1·22	0·89	0·75, 1·07	0·92	0·76, 1·10	0·93	0·77, 1·13
Q4	1465	1·42	1·20, 1·68	1·13	0·95, 1·34	1·16	0·97, 1·38	1·17	0·97, 1·41
Q5	1465	1·41	1·19, 1·66	0·99	0·83, 1·18	1·01	0·85, 1·21	1·06	0·88, 1·28
P_{trend}		<0·001		0·797		0·978		0·611	

*Model 1: adjusted for energy, age and gender.
†Model 2: additionally adjusted for marital status, education, smoking, family size, house possession, night working shift, physical activity, supplement use, history of depression and thyroid diseases.
‡Model 3: further adjustment for BMI.

Earlier studies on the link between nutrients and MetS have been mostly limited to individual nutrient intake[36–38]. NP analysis is a new approach in nutrition epidemiology that covers the intake of all nutrients in addition to their interactions[21]. Previous studies on the NP named the patterns based on the nutrients loaded in each pattern, for example, B vitamins-rich NP, vitamin and fibre NP, carbohydrate-rich NP, animal product NP. In the current study, we found three NP with a very complex set of nutrients that made our interpretation somewhat difficult. In NP1, sixteen nutrients including P; vitamins B_1, B_3, B_6 and B_5; Se; Mg; Fe; protein; Cr; Cu; dietary fibre; biotin; Mn; Zn and Na were loaded. We can label it as a semi-plant NP because plant-based foods such as whole grains, vegetables, legumes and nuts contain a high amount of these nutrients. However, this pattern may have a high amount of animal protein because of phosphorous and protein loaded. Overall, the interactions between these nutrients with neutral, MetS-inducing[25,39] and MetS-protecting effects[40,41] resulted in a non-significant association between NP1 and MetS. This was the case for NP3 that was not significantly associated with MetS. NP3 was rich in carbohydrate and refined sugar, and poor in vitamin E, MUFA, PUFA and SFA resulting in, we labelled it as, a high-carbohydrate/low-fat NP.

In the current study, we found a significant positive association between NP2 and odds of MetS. This pattern was characterised by the high intakes of Ca; K; vitamins B_2, B_{12}, A, D, K and C; SFA; dietary cholesterol and TFA. We labelled it as a semi-animal NP because the majority of nutrients in this pattern are present in animal-based foods. However, K and vitamins C and K are mostly available in plant-based foods. Dietary intakes of SFA, TFA and dietary cholesterol have been positively related to MetS in the previous studies[42,43]. In contrast, there is evidence indicating an inverse association between Ca; K and vitamins B_{12}, B_2, C and D with MetS[6,44–47]. In regard to Ca and MetS, there is a controversy; some studies presented a protective association, while others failed to find a significant association between dietary Ca intake and MetS[48,49]. The combination of nutrients with neutral (vitamins A and K), MetS-protecting (Ca, K and vitamins B_{12}, B_2, C and D) and MetS-inducing (SFA, TFA and dietary cholesterol) effects in NP2 made our interpretation complicated. However, the overall effect of this pattern, by considering the interactions between nutrients, increased the odds of MetS. It should be kept in mind that patients with MetS might change their diet to alleviate the components of MetS, and this issue might be a reason for the presence of MetS-protecting nutrients in this pattern.

Several mechanisms have been reported for the role of nutrients in MetS. Saturated fat intake increases the NEFA concentration in serum and induces insulin resistance as the main risk factor for MetS[50]. Dietary intake of TFA contributes to increased risk of dyslipidaemia, hypertension and consequently MetS[51,52]. Findings from experimental studies revealed that animal protein intake was positively associated with the low-grade inflammation which is a known risk factor for all components of MetS including abdominal obesity, hypertension, dyslipidaemia and hyperglycaemia[53,54].

The current study has several strengths. The current study was the first comprehensive study with a large sample size to examine the association between NP and MetS in the Middle East. We controlled for a wide range of potential confounders. However, the potential effects from residual confounders cannot be excluded. We collected questionnaire-based information via face-to-face interviews for increasing the accuracy of data. However, some limitations should be considered when interpreting our findings. The nature of our study was cross-sectional, and therefore we cannot confer a causal link between NP and MetS because of the transposition of exposure and outcome. Further studies with prospective designs are required to confirm our findings. In the current study, patients with MetS might have changed their diet to manage lipid profile and blood pressure or to lose weight. However, this confounding effect would tend to attenuate the effect sizes; therefore, the true estimates may be even stronger than those obtained. In addition, like other epidemiological studies, the existence of measurement error and misclassification of study participants cannot be excluded in the current study as well. However, we used a validated FFQ for the assessment of dietary intakes.

In conclusion, we found that adherence to a semi-animal NP characterised by the high intakes of Ca; K; vitamins B_2, B_{12}, A, D, K and C; SFA; dietary cholesterol and TFA was positively associated with MetS. Further studies, particularly those with a prospective design, are required to confirm our findings.

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References

1. Li X, Li X, Lin H *et al.* (2017) Metabolic syndrome and stroke: a meta-analysis of prospective cohort studies. *J Clin Neurosci* **40**, 34–38.
2. Gonzalez-Chavez A, Chavez-Fernandez JA, Elizondo-Argueta S *et al.* (2018) Metabolic syndrome and cardiovascular disease: a health challenge in Mexico. *Arch Med Res* **49**, 516–521.
3. Obunai K, Jani S & Dangas GD (2007) Cardiovascular morbidity and mortality of the metabolic syndrome. *Med Clin North Am* **91**, 1169–1184, x.
4. Goolam Mahyoodeen N, Crowther NJ, Snyman T *et al.* (2018) High burden of the metabolic syndrome and its component disorders in South Africans with psoriasis. *Int J Dermatol* **58**, 557–562.
5. Ford ES, Li C & Zhao G (2010) Prevalence and correlates of metabolic syndrome based on a harmonious definition among adults in the US. *J Diabetes* **2**, 180–193.
6. Mansouri M, Abasi R, Nasiri M *et al.* (2018) Association of vitamin D status with metabolic syndrome and its components: a cross-sectional study in a population of high educated Iranian adults. *Diabetes Metab Syndr* **12**, 393–398.
7. Abou Ziki MD & Mani A (2016) Metabolic syndrome: genetic insights into disease pathogenesis. *Curr Opin Lipidol* **27**, 162–171.
8. Thoefner LB, Rostved AA, Pommergaard HC *et al.* (2018) Risk factors for metabolic syndrome after liver transplantation: a systematic review and meta-analysis. *Transplant Rev* **32**, 69–77.
9. Anjom-Shoae J, Keshteli AH, Sadeghi O *et al.* (2020) Association between dietary insulin index and load with obesity in adults. *Eur J Nutr* **59**, 1563–1575.
10. Mansouri M, Sharifi F, Yaghubi H *et al.* (2019) Sugar-sweetened beverages consumption in relation to hypertension among Iranian university students: the MEPHASOUS study. *Eat Weight Disord* (Epublication ahead of print version 21 May 2019). doi: 10.1007/s40519-019-00713-9.
11. Parohan M, Sadeghi A, Nasiri M *et al.* (2019) Dietary acid load and risk of hypertension: a systematic review and dose-response meta-analysis of observational studies. *Nutr Metab Cardiovasc Dis* **29**, 665–675.
12. Sadeghi O, Sadeghian M, Rahmani S *et al.* (2019) Whole-grain consumption does not affect obesity measures: an updated systematic review and meta-analysis of randomized clinical trials. *Adv Nutr* **11**, 280–292.
13. Suriyaprom K, Kaewprasert S, Putpadungwipon P *et al.* (2019) Association of antioxidant status and inflammatory markers with metabolic syndrome in Thais. *J Health Popul Nutr* **38**, 1.
14. Luan D, Wang D, Campos H *et al.* (2020) Red meat consumption and metabolic syndrome in the Costa Rica Heart Study. *Eur J Nutr* **59**, 185–193.
15. Kim MK, Chon SJ, Noe EB *et al.* (2017) Associations of dietary calcium intake with metabolic syndrome and bone mineral

Public Health Nutrition

density among the Korean population: KNHANES 2008–2011. *Osteoporos Int* **28**, 299–308.
16. Hosseinpour-Niazi S, Mirmiran P, Hosseini-Esfahani F *et al.* (2016) Is the metabolic syndrome inversely associates with butter, non-hydrogenated- and hydrogenated-vegetable oils consumption: Tehran lipid and glucose study. *Diabetes Res Clin Pract* **112**, 20–29.
17. Dabbagh-Moghadam A, Mozaffari-Khosravi H, Nasiri M *et al.* (2017) Association of white and red meat consumption with general and abdominal obesity: a cross-sectional study among a population of Iranian military families in 2016. *Eat Weight Disord* **22**, 717–724.
18. Parohan M, Anjom-Shoae J, Nasiri M *et al.* (2019) Dietary total antioxidant capacity and mortality from all causes, cardiovascular disease and cancer: a systematic review and dose-response meta-analysis of prospective cohort studies. *Eur J Nutr* **58**, 2175–2189.
19. Zhang Y & Zhang DZ (2019) Relationship between nut consumption and metabolic syndrome: a meta-analysis of observational studies. *J Am Coll Nutr* **38**, 499–505.
20. Hosseinpour-Niazi S, Mirmiran P, Amiri Z *et al.* (2012) Legume intake is inversely associated with metabolic syndrome in adults. *Arch Iran Med* **15**, 538–544.
21. Willett W (2012) *Nutritional Epidemiology*, vol. 40. Oxford UK: Oxford University Press.
22. Malmir H, Shayanfar M, Mohammad-Shirazi M *et al.* (2019) Patterns of nutrients intakes in relation to glioma: a case–control study. *Clin Nutr* **38**, 1406–1413.
23. Freisling H, Fahey MT, Moskal A *et al.* (2010) Region-specific nutrient intake patterns exhibit a geographical gradient within and between European countries. *J Nutr* **140**, 1280–1286.
24. McNaughton SA (2010) Dietary patterns and diet quality: approaches to assessing complex exposures in nutrition. *Australasian Epidemiol* **17**, 35.
25. Bian S, Gao Y, Zhang M *et al.* (2013) Dietary nutrient intake and metabolic syndrome risk in Chinese adults: a case–control study. *Nutr J* **12**, 106.
26. Khayyatzadeh SS, Moohebati M, Mazidi M *et al.* (2016) Nutrient patterns and their relationship to metabolic syndrome in Iranian adults. *Eur J Clin Invest* **46**, 840–852.
27. Ghorabi S, Salari-Moghaddam A, Daneshzad E *et al.* (2019) Association between the DASH diet and metabolic syndrome components in Iranian adults. *Diabetes Metab Syndr* **13**, 1699–1704.
28. Sadeghi O, Keshteli AH, Doostan F *et al.* (2018) Association between dairy consumption, dietary calcium intake and general and abdominal obesity among Iranian adults. *Diabetes Metab Syndr* **12**, 769–775.
29. Esmaillzadeh A & Azadbakht L (2008) Major dietary patterns in relation to general obesity and central adiposity among Iranian women. *J Nutr* **138**, 358–363.
30. Poustchi H, Eghtesad S, Kamangar F *et al.* (2018) Prospective epidemiological research studies in Iran (the PERSIAN cohort study): rationale, objectives, and design. *Am J Epidemiol* **187**, 647–655.
31. Esfahani FH, Asghari G, Mirmiran P *et al.* (2010) Reproducibility and relative validity of food group intake in a food frequency questionnaire developed for the Tehran Lipid and Glucose Study. *J Epidemiol* **20**, 150–158.
32. US Food and Drug Administration (1999) *Whole-Grain Foods Authoritative Statement Claim Notification*. Washington, DC: US Department of Agriculture.
33. Moghaddam MB, Aghdam FB, Jafarabadi MA *et al.* (2012) The Iranian version of International Physical Activity Questionnaire (IPAQ) in Iran: content and construct validity, factor structure, internal consistency and stability. *World Appl Sci J* **18**, 1073–1080.
34. Grundy SM, Cleeman JI, Daniels SR *et al.* (2005) Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute scientific statement: executive summary. *Crit Pathw Cardiol* **4**, 198–203.
35. Azizi F, Hadaegh F, Khalili D *et al.* (2010) Appropriate definition of metabolic syndrome among Iranian adults: report of the Iranian National Committee of Obesity. *Arch Iran Med* **13**, 426–428.
36. Moore-Schiltz L, Albert JM, Singer ME *et al.* (2015) Dietary intake of calcium and magnesium and the metabolic syndrome in the National Health and Nutrition Examination (NHANES) 2001–2010 data. *Br J Nutr* **114**, 924–935.
37. Li X, Guo B, Jin D *et al.* (2018) Association of dietary sodium: potassium ratio with the metabolic syndrome in Chinese adults. *Br J Nutr* **120**, 612–618.
38. Lee M, Lee H & Kim J (2018) Dairy food consumption is associated with a lower risk of the metabolic syndrome and its components: a systematic review and meta-analysis. *Br J Nutr* **120**, 373–384.
39. Lim HS, Shin EJ, Yeom JW *et al.* (2017) Association between nutrient intake and metabolic syndrome in patients with colorectal cancer. *Clin Nutr Res* **6**, 38–46.
40. Chen JP, Chen GC, Wang XP *et al.* (2017) Dietary fiber and metabolic syndrome: a meta-analysis and review of related mechanisms. *Nutrients* **10**, 24.
41. Wei B, Liu Y, Lin X *et al.* (2018) Dietary fiber intake and risk of metabolic syndrome: a meta-analysis of observational studies. *Clin Nutr* **37**, 1935–1942.
42. Nybacka A, Hellstrom PM & Hirschberg AL (2017) Increased fibre and reduced trans fatty acid intake are primary predictors of metabolic improvement in overweight polycystic ovary syndrome – substudy of randomized trial between diet, exercise and diet plus exercise for weight control. *Clin Endocrinol* **87**, 680–688.
43. Guo Z, Miura K, Turin TC *et al.* (2010) Relationship of the polyunsaturated to saturated fatty acid ratio to cardiovascular risk factors and metabolic syndrome in Japanese: the INTERLIPID study. *J Atheroscler Thromb* **17**, 777–784.
44. Wieder-Huszla S, Jurczak A, Szkup M *et al.* (2019) Relationships between vitamin D(3) and metabolic syndrome. *Int J Environ Res Public Health* **16**, 175.
45. Guarnizo-Poma M, Urrunaga-Pastor D, Montero-Suyo C *et al.* (2018) Association between serum vitamin B_{12} levels and metabolic syndrome in a euthyroid population. *Diabetes Metab Syndr* **12**, 943–948.
46. Park S, Ham JO & Lee BK (2015) Effects of total vitamin A, vitamin C, and fruit intake on risk for metabolic syndrome in Korean women and men. *Nutrition* **31**, 111–118.
47. Li Z, Gueant-Rodriguez RM, Quilliot D *et al.* (2018) Folate and vitamin B_{12} status is associated with insulin resistance and metabolic syndrome in morbid obesity. *Clin Nutr* **37**, 1700–1706.
48. Gomes JMG, Costa JDA & Alfenas RCG (2018) Effect of increased calcium consumption from fat-free milk in an energy-restricted diet on the metabolic syndrome and cardiometabolic outcomes in adults with type 2 diabetes mellitus: a randomised cross-over clinical trial. *Br J Nutr* **119**, 422–430.
49. Shin BR, Choi YK, Kim HN *et al.* (2016) High dietary calcium intake and a lack of dairy consumption are associated with metabolic syndrome in obese males: the Korean National Health and Nutrition Examination Survey 2010 to 2012. *Nutr Res* **36**, 518–525.
50. Yang WS, Chen PC, Hsu HC *et al.* (2018) Differential effects of saturated fatty acids on the risk of metabolic syndrome: a matched case-control and meta-analysis study. *Metabolism* **83**, 42–49.
51. Ooi EM, Watts GF, Ng TW *et al.* (2015) Effect of dietary Fatty acids on human lipoprotein metabolism: a comprehensive update. *Nutrients* **7**, 4416–4425.

Public Health Nutrition

52. Mazidi M, Wong ND, Katsiki N *et al.* (2017) Dietary patterns, plasma vitamins and trans fatty acids are associated with peripheral artery disease. *Lipids Health Dis* **16**, 254.
53. Mu WC, VanHoosier E, Elks CM *et al.* (2018) Long-term effects of dietary protein and branched-chain amino acids on metabolism and inflammation in mice. *Nutrients* **10**, 918.
54. Tak KH, Ahn E & Kim E (2017) Increase in dietary protein content exacerbates colonic inflammation and tumorigenesis in azoxymethane-induced mouse colon carcinogenesis. *Nutr Res Pract* **11**, 281–289.

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