Magnesium intake and prevalence of metabolic syndrome in adults: Tehran Lipid and Glucose Study

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Abstract

Objective: We examined the association of metabolic syndrome (MetS) and its components with dietary intakes of Mg in Tehran adults.

Design: In a cross-sectional study, dietary intakes were assessed using a valid and reliable FFQ. MetS was defined according to the modified guidelines of the National Cholesterol Education Program Adult Treatment Panel III. Waist circumference (WC) was coded according to the newly introduced cut-off points for Iranian adults (≥95 cm for both genders).

Setting: Participants of the Tehran Lipid and Glucose Study (2006–2008).

Subjects: Adults (*n* 2504; 1120 men and 1384 women) aged 18–74 years.

Results: The mean age of participants was 40·8 (SD 14·6) years and 38·2 (SD 13·5) years for men and women, respectively. The reported mean intake of Mg was 349 (SD 109) mg/d. After adjustment for confounding factors, dietary Mg intake was inversely associated with fasting blood glucose ($\beta = -0.08$, $P = 0.006$), TAG ($\beta = -0.058$, $P = 0.009$) and WC ($\beta = -0.013$, $P = 0.006$); however, there were no associations between dietary Mg and diastolic blood pressure, systolic blood pressure or HDL cholesterol. An association was observed between MetS Z-score and Mg intake (crude $\beta = -0.017$, $P = 0.001$), independent of age, gender, smoking, physical activity and BMI; this association was attenuated following further adjustment for dietary factors and menopausal status ($\beta = -0.034$, $P = 0.061$).

Conclusions: Our findings suggest a significant inverse association between dietary Mg, MetS and its components.

Keywords
Magnesium intake
Metabolic syndrome
Risk factors
Adults

Mg plays an important role in numerous physiological processes. It is a cofactor for various enzymes that are involved in muscle contraction, neurotransmitter release and the regulation of ion channels. Almost ubiquitous in foods, the primary dietary sources for Mg are wholegrain cereals, legumes, nuts and chocolate. Fruits, meats, other vegetables and fish have intermediate levels of Mg, and dairy products and beverages have low Mg content. The medical significance of marginal Mg intake on human health has not been confirmed[1].

According to the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) criteria[2], metabolic syndrome (MetS), defined by the presence of three or more of the five components of (i) dysglycaemia, (ii) raised blood pressure, (iii) elevated TAG levels, (iv) low HDL cholesterol (HDL-C) levels and (v) obesity (particularly central adiposity), which leads to a greatly increased risk of future CVD and diabetes, is considered one of the major public health challenges worldwide[3]. The prevalence of MetS in Tehranian adults is over 30 %[4]. Previous studies report that higher intakes of Mg and its major food sources, such as whole grains[5], are associated with lower risk of type 2 diabetes[6,7], blood pressure[7,8], CVD[9,10] and insulin resistance[11]. Mg has been postulated to play a role in glucose homeostasis, insulin resistance and lipid metabolism[12,13], and an inverse association between Mg intake and MetS has been reported previously[14,15]. Populations with various dietary patterns and genetic backgrounds could have different risks for MetS[16]. Most data related to the association between Mg intake and MetS come from Western populations[17]. Therefore investigating these associations between nutrients and risk of MetS in various populations seems to be critical. Regarding the nutritional transition in Iran towards increased consumption of refined starches, low fruit and vegetable intakes and high SFA intakes[18], and considering the limited population-based data available on

the relationship between Mg intake and MetS in Asia, the present study was conducted to evaluate the relationship between dietary Mg intake, MetS and its components.

Participants and methods

The Tehran Lipid and Glucose Study (TLGS) is a community-based study of individuals, aged ≥3 years, under coverage of three medical health centres in district no. 13 of Tehran, the capital city of Iran. Following baseline collection of data, the prospective ongoing phases aimed at preventing non-communicable diseases by the development of programmes promoting healthy lifestyles to reduce non-communicable disease risk factors[19]. The present study was conducted on a sample of residents who participated in the third phase of the TLGS. Of a total of 12 523 individuals who completed the examinations during the third phase of TLGS (2006–2008), 4920 were randomly selected for our study for dietary assessment based on their age and sex. Selection was done because of the cost and complexity of dietary data collection and the time-consuming nature of this process. Finally, dietary data of 3462 individuals who agreed to participate and completed the FFQ were available. Characteristics of participants who completed the dietary assessment were similar to those of the total population in the third phase of TLGS[20]. For the purpose of the present study, 2881 individuals, aged 18–74 years, were selected. Baseline exclusion criteria included a history of diabetes, CVD or stroke (*n* 98); we also excluded 118 individuals whose reported daily energy intakes were not within the range of 3347–17 573 kJ/d (800–4200 kcal/d), and those with missing values of weight, height or other variables (*n* 161). Finally, a total of 2504 individuals remained for the current analysis. Trained interviewers carried out face-to-face private interviews with participants, using pre-tested questionnaires concerning age, medical history, current use of medications and smoking habits[19]. Informed written consent was obtained from each participant, and the proposal of the present study was approved by the Research Institute of Endocrine Sciences, Shahid Beheshti University of Medical Sciences.

Physical activity

To obtain various measurements of energy expenditure and physical activity, Kriska's physical activity questionnaire was used[21]. Participants were asked to identify the frequency and time spent during the previous year on activities of light, moderate, hard and very hard intensity, according to a list of common activities of daily life, and the metabolic equivalent (MET) was calculated according to the compendium of physical activities[22].

Dietary assessment

Dietary data were collected by means of a validated semi-quantitative FFQ, which contained 168 food items. The adjusted Pearson correlation coefficients of Mg intake estimated by the average of twelve 24 h dietary recalls and the FFQ were 0·65 and 0·35 for men and women, respectively. The age- and energy-adjusted intraclass correlations for Mg intake between two FFQ over a 14-month interval were 0·61 and 0·59 for men and women, respectively[23].

Food and beverages were quantified using household measures. Portion sizes of consumed foods were converted from household measures to grams[24]. All questionnaires, administered by trained dietitians who had ≥5 years' experience in the TLGS, asked participants to designate their consumption frequency for each food item consumed during the previous year on a daily, weekly or monthly basis. Since the Iranian food composition table (FCT) is incomplete and has limited data on nutrient content of raw foods and beverages[25], foods and beverages were analysed for their energy and nutrient content using the US Department of Agriculture (USDA) FCT[26]; however, the Iranian FCT was used for some dairy products (like *Kashk*), which are not listed in USDA FCT[25]. Moreover, the nutrient content of mixed food items (e.g. pizza) was calculated according to usual restaurant recipes.

Anthropometric measurements

Body weight was measured to the nearest 0·1 kg with digital scales (Seca, Hamburg, Germany) while the participants were minimally clothed, without shoes. Height was measured in a standing position without shoes while the shoulders were in a normal state using a stadiometer (model 208 portable body meter measuring device; Seca). BMI was calculated from measured weight and height. Waist circumference (WC) was measured at the umbilical site using an outstretched tape meter and without pressure to body surfaces, and was recorded to the nearest 0·1 cm. All measurements were carried out by one examiner for women and one for men to avoid random observer error.

Blood pressure was assessed according to the standard protocol[27]. Additional covariate information regarding age, smoking habits, physical activity, medical history and current use of medication was obtained using questionnaires[19].

Biochemical measurements

A fasting blood sample was drawn from each participant after >12 h overnight fasting for the measurement of glucose and lipid concentration[19]. Fasting blood glucose (FBG) was measured with an enzymatic colorimetric method using glucose oxidase. Serum TAG concentrations were assayed with the use of TAG kits (Pars Azmoon, Inc., Tehran, Iran) adapted to the Selectra 2 auto-analyser (Vital Scientific, Spankeren, The Netherlands). HDL-C was measured after precipitation of the apoB-containing lipoproteins with phosphotungstic acid. Monitoring of assay performance was done once every twenty tests, using lipid control serum, Percinorm (normal range) and Percipath (pathological range) wherever applicable (catalogue no. 1446070 for Percinorm and 171778 for Percipath; Boehringer Mannheim, Germany). Lipid standard (Cfas, catalogue no. 759350;

Boehringer Mannheim) was used to calibrate the Selectra 2 auto-analyser daily at laboratory analyses and all samples were analysed when internal quality control met the acceptable criteria. Inter- and intra-assay CV were 1·6 and 0·6 % for TAG, respectively[28].

Definition of the metabolic syndrome

MetS was determined according to the modified NCEP ATP III definition[29]. Participants with three or more of the following conditions were typically defined as having MetS: (i) TAG ≥150 mg/dl, (ii) HDL-C <40 mg/dl in men and <50 mg/dl in women; (iii) elevated blood pressure, ≥130/85 mmHg; and (iv) abnormal glucose homeostasis, FBG ≥110 mg/dl. We coded WC according to the newly introduced cut-off points for Iranian adults (≥95 cm for both genders) but did not consider this coding in calculating the final MetS risk factor clustering, due to a lack of relevant information[29].

Statistical analysis

Statistical analyses were performed using the SPSS statistical software package version 16 (SPSS Inc., Chicago, IL, USA) on the data of 2504 adult participants. Normality was checked for all variables. The participants were categorized according to quartile of Mg intake (<268, 269–341, 342–426 and ≥427 mg/d). The mean (SD) value of each MetS risk factor in gender and age categories was calculated and compared using Student's t test.

Stratified analyses were performed to evaluate the possible modifying effect of age on the association between Mg intake and MetS, because the age of the participants may contribute to the discrepancies; older participants may be a select group who may be less vulnerable to environmental factors. The interaction between Mg intake and metabolic risk factors by gender was statistically significant. Therefore, we analysed data for the association between MetS and Mg intake stratified by gender and age. The interaction between Mg and dietary fibre was significant. Hence, we also analysed data for the association between MetS Z-score and Mg intake stratified by dietary fibre. Participants were stratified into high and low fibre intake according to the median (32 g/d).

Significant differences in general characteristics across quartile categories of Mg intake were evaluated by using one-way ANOVA with Tukey *post hoc* comparisons. We used the χ^2 test for qualitative variables to detect significant differences in the distribution of participants across quartiles of Mg intake, adjusted for energy as mg/4184 kJ (1000 kcal).

A continuous MetS risk Z-score was derived by standardizing and then summing the following continuously distributed indices of obesity: (BMI + WC/2), hypertension (systolic blood pressure + diastolic blood pressure/2), FBG, HDL-C and TAG[30]. A Z-score was computed as the number of SD units from the sample mean after normalization of the variables, i.e. $Z = [(\text{value} - \text{mean})/\text{SD}]$, for each of these variables. The Z-scores of systolic and diastolic blood pressure were averaged. This sum was then divided by six to compile the MetS risk score with units of SD.

Multiple linear regression analysis was used to assess the relationship between dietary Mg intake and each metabolic risk factor. Three models were constructed: model 1 was crude β; model 2 was adjusted for age, gender, smoking status and physical activity; and model 3 was additionally adjusted for total fibre, SFA, K, Ca, Na, oestrogen use, menopausal status, fish and food groups. The variables age, WC and physical activity score were entered in all models as continuous variables, while gender and smoking status were used as categorical variables.

To ascertain the association of Mg intake with MetS, logistic regression models controlled for age, gender, smoking status, physical activity, dietary fibre, SFA, K, Ca, Na, oestrogen use, menopausal status, fish and food groups were used.

Results

The study population was composed of 43·3 % men and 56·7 % women (1120 men and 1384 women) with mean ages of 40·8 (SD 14·6) years and 38·2 (SD 13·5) years, respectively. Mean (SD) intakes of Mg in men and women were 367 (SD 109) and 336 (SD 107) mg/d, respectively. In this population the Mg intake of 57·2 % was higher than the RDA of 320 mg/d (data not shown). Characteristics of the study population according to dietary Mg quartile are shown in Table 1. Baseline characteristics were not significantly different across quartiles of Mg intake. Dietary intakes of participants according to quartile of Mg intake are shown in Table 2. Those in the upper quartile of Mg intake per 4184 kJ (1000 kcal) had higher intakes of energy, fat, fibre and foods rich in Mg. Abnormal mean/median values for each of the MetS risk factors and the percentage of individuals with abnormal parameters are presented in Table 3. Men had significantly higher mean values for three of the five MetS risk factors and lower mean value for HDL-C concentration in the ≤50 years age category than did women; they also had significantly higher mean values for two of the five MetS risk factors and lower mean value for HDL-C concentration in the >50 years age category. Low HDL-C concentration was the most prevalent MetS risk factor among both men and women.

Table 4 shows that Mg intake was inversely associated with increase in FBG, WC and MetS Z-score in analyses adjusted for confounding variables (model 2). Although additional adjustment for dietary fibre, SFA, K, Ca, NA, oestrogen use, menopausal status, fish and food groups (model 3) did not affect associations between Mg intake, FBS and WC, the associations were attenuated. Mg intake was inversely associated with MetS Z-score and WC in obese individuals, but this relationship was not significant in participants with normal weight.

Table 1 Baseline characteristics of participants according to quartile of magnesium intake: men and women aged 18–74 years, Tehran Lipid and Glucose Study

| | Mg intake (mg/4184 kJ (1000 kcal)) | | | | | | | |
| | Q1 ≤140 | | Q2 140–160 | | Q3 160–180 | | Q4 ≥180 | |
Characteristic	Mean or *n*	SD or %	Mean or *n*	SD or %	Mean or *n*	SD or %	Mean or *n*	SD or %
No. of participants	632		624		617		631	
Age (years)*	39·2	14	39·7	14	39·2	14	39	14
Women (*n*; %)	231	65·3	267	59·5	296	54·7	250	47·2
BMI (kg/m²)*	26·5	4·8	27·3	4·8	27·2	5·3	26·8	5·2
Physical activity (MET)*	38·4	56	36·2	86	36·6	55	34·4	47
Current smokers (*n*; %)	64	11·1	44	8	63	11·8	53	9·5
Obese (*n*; %)†	134	22·5	151	27	142	25	122	25·5
Overweight (*n*; %)‡	203	40·8	201	42·6	213	43·6	220	44·8

MET, metabolic equivalent.
*Data are mean and SD, unless otherwise specified. *P* values for tests of difference across all quartiles (ANOVA and Tukey's *post hoc* test for data that are mean and SD; χ^2 test for data that are percentages) were not significant.
†Obesity was defined as BMI ≥ 30·0 kg/m².
‡Overweight was defined as BMI = 25·0–29·9 kg/m².

Table 2 Dietary intakes of participants according to quartile of magnesium intake: men and women aged 18–74 years, Tehran Lipid and Glucose Study

| | Mg intake (mg/4184 kJ (1000 kcal)) | | | | | | | | |
| | Q1 ≤140 | | Q2 140–160 | | Q3 160–180 | | Q4 ≥180 | | |
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P**
No. of participants	632		624		617		631		
Total energy (kJ/d)	8263	2602	9372	2506	10 305	2381	11 406	2527	0·001
Total energy (kcal/d)	1975	622	2240	599	2463	569	2726	641	0·001
Total fat (g/d)	64	27	75	32	84	33	95	34	0·04
Cholesterol (mg/d)	126	118	164	151	183	146	201	163	0·03
Fibre (g/d)	6·04	2·2	7·21	5·5	7·73	2·3	9·20	3·7	0·04
Ca (mg/d)	477	160	573	197	679	201	815	277	0·02
K (mg/d)	1599	450	1984	473	2362	508	2869	889	0·001
Na (g/d)†	3·1	3·0	4·3	3·4	4·5	3·1	5·0	2·8	0·001
Fruits (g/d)‡	196	8	205	10	228	9	245	11	0·03
Vegetables (g/d)§	261	10	324	11	343	9	362	13	0·04
Coffee (ml/d)	6·5	24	10·8	32	11·2	36	21·0	63	0·001
Tea (ml/d)	446	332	540	432	611	462	745	545	0·001
Grains (g/d)‖	208	8	238	10	242	12	260	14	0·03
Milk and milk products (ml/d)¶	262	167	392	205	487	267	583	353	0·002
Meat (g/d)**	13·2	11·3	16·3	17·4	16·3	17·4	25·3	27	0·05
Chicken (g/d)	20·0	21	25·2	25	27·5	28	37·7	50	0·04
Liver (g/d)	0·26	1·7	0·30	1·5	0·45	2·4	0·51	2·5	0·04
Fish (g/d)††	4·3	7	5·8	10	6·6	9	10·3	33	0·04
Eggs (g/d)	10·0	10	13·5	14	14·4	13	18·7	18	0·04

*P for differences among Mg quartiles (ANOVA with Tukey's *post hoc* test), significantly different from the first quartile.
†Including Na in foods and added salt during preparing foods, not Na added at the table.
‡Includes apples, oranges, bananas, peaches, grapes, strawberries, pears, watermelon, grapefruit, prunes, pomegranates, kiwi, persimmons, raisins, figs, coconuts, apricots, sweet lemon and lemon.
§Includes onions, cucumbers, lettuce, carrots, cauliflower, Brussel sprouts, kale, cabbage, spinach, mixed vegetables, corn, green beans, green peas, peppers, beets, potatoes, tomatoes, broccoli and celery.
‖Includes dark and white breads.
¶Includes milk, yoghurt and cheese.
**Includes beef hamburger, sausages, processed meats, meat in a sandwich.
††Includes tuna fish and other fish.

After adjustment for covariates following logistic regression analysis, no association was found between Mg intake and MetS (data not shown). After stratifying by age, the association between Mg intake and MetS remained significant and was not affected by confounders in those aged >50 years (*P* < 0·001, Table 5).

In participants with high dietary fibre intake, Mg intake was associated inversely with MetS ($\beta = -0\cdot004$,

Table 3 Distribution of participants with abnormal values* for each component of the metabolic syndrome according to gender and age group: men and women aged 18–74 years, Tehran Lipid and Glucose Study

	FBG			TAG†			SBP			DBP			HDL-C			WC		
Characteristic	Mean	SD	%	Median	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%
Men																		
Age ≤ 50 years (n 834)	147·6	44	30·7	2·4‡	0·15	54·0	137	9·2	9·2	91·2	6·5	15·2	33‡	4·0	58·9	103‡	7·0	68·7
Age > 50 years (n 329)	154·4	46	8·9	2·4‡	0·16	41·2	146‡	14·4	37·9	93·4	7·5	27·5	34‡	7·5	60·7	104‡	7·0	47·0
Women																		
Age ≤ 50 years (n 1012)	162·3	57	31·3	2·3	0·12	46·2	137	7·6	3·3	90·3	4·7	5·5	34	3·7	68·2	102	6·2	58·9
Age > 50 years (n 329)	154·0	46	7·6	2·3	0·13	19·6	144	14·5	34·3	91·5	6·5	18·6	40	6·3	67·8	102	7·5	16·3

FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, HDL cholesterol; WC, waist circumference.
*Abnormal values defined as: FBG ≥ 100 mg/dl; TAG ≥ 150 mg/dl; SBP ≥ 130 mmHg; DBP ≥ 85 mmHg; HDL-C <40 mg/dl in men and <50 mg/dl in women; WC ≥ 95 cm for both genders.
†Log-transformed values were used for analysis.
‡Value was significantly different from that of women in the same age group: $P < 0.05$.

Table 4 Multiple linear regression analysis of the association between dietary magnesium intake and metabolic syndrome outcomes: men and women aged 18–74 years, Tehran Lipid and Glucose Study

Outcome per unit increase in Mg intake (mg/4184 kJ (1000 kcal))	Model 1*			Model 2*			Model 3*		
	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P
FBG	−0·09	−0·128, −0·074	0·001	−0·06	−0·014, −0·075	0·004	−0·08	−0· 76, −0·017	0·006
TAG†	−0·021	−0·69, 0·055	0·32	−0·019	−0·162, 0·054	0·36	−0·058	−0·33, −0·065	0·009
HDL-C	−0·005	−0·014, 0·010	0·78	−0·011	−0·009, −0·016	0·58	−0·029	−0·017, −0·006	0·44
DBP	0·025	0·006, 0·031	0·005	−0·023	−0·021, −0·005	0·24	−0·080	−0·015, −0·008	0·37
SBP	0·042	0·028, 0·068	0·001	−0·019	0·305, −0·029	0·30	−0·070	−0·029, −0·018	0·62
WC	0·099	0·025, 0·058	0·001	−0·032	−0·021, −0·006	0·001	−0·013	−0·024, −0·007	0·006
WC in participants									
Obese‡	−0·046	−0·052, −0·001	0·001	−0·028	−0·042, −0·013	<0·001	−0·037	−0·04, −0·007	0·005
Non-obese	0·037	−0·012, 0·034	0·36	0·051	−0·008, 0·038	0·21	0·083	−0·003, 0·051	0·083
MetS risk Z-score	−0·017	0·001, 0·023	0·001	−0·027	−0·07, −0·004	0·01	−0·034	−0·03, −0·000	0·061
MetS risk Z score in participants									
Obese‡	−0·004	−0·006, −0·001	<0·001	−0·006	−0·005, −0·001	0·006	−0·014	−0·032, −0·001	0·035
Non-obese	−0·025	−0·003, 0·002	0·65	−0·040	−0·002, 0·001	0·35	−0·011	−0·001, 0·001	0·31

FBG, fasting blood glucose; HDL-C, HDL cholesterol; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference; MetS, metabolic syndrome.
*Model 1, crude β; model 2, adjusted for, age, gender, smoking status, physical activity and BMI; model 3, adjusted as in model 2 plus total fibre intake, SFA, Na, K, Ca, oestrogen use, menopausal status, fish and food groups. BMI excluded from model 2 and 3 for MetS Z-score and WC analysis.
†Log-transformed values were used for analysis.
‡Obesity was defined as BMI ≥ 30·0 kg/m².

$R^2 = 0.25$, $P = 0.02$) in model 3. However in the low fibre intake group we did not observe any significant association (Table 5).

Discussion

In the present cross-sectional study conducted in a group of inhabitants of Tehran, there were significant inverse associations between Mg intake and three MetS components including FBG, WC and TAG. An association between MetS *Z*-score and Mg intake was observed, independent of confounding variables; however further adjusting for dietary factors attenuated this association.

Many observational studies have reported the beneficial effect of Mg intake on reducing prevalence of MetS. Two cross-sectional studies reported an inverse association between dietary Mg and MetS prevalence among adults[14] and older Americans[15]. In the Women's Health Study, higher Mg intake was associated with a 27 % lower risk of having MetS[31]. Also a population-based study from southern Europe of middle-aged healthy individuals reported that participants in the lowest tertile of Mg intake were three times more likely to have MetS than those in the highest tertile after adjustment for demographic, clinical and environmental factors; however, this association disappeared after controlling for dietary fibre intake[32]. Mg intake may reduce risk of MetS by beneficial defects on endothelial function and systematic inflammation; that has been shown to be closely associated with insulin resistance[32,33].

In our sample of community-living adults, however, we observed no relationship between dietary Mg intake and hypertension. This may in part be due to the different age groups we studied.

The three components of MetS associated with dietary Mg intake were FBG, TAG and WC. Experimental studies suggest that Mg may lead to improvements in glucose control and insulin sensitivity among type 2 diabetes patients[34,35] and healthy older adults[15,36].

In our study, FBG was inversely associated with dietary Mg intake. In a cross-sectional study in older adults (≥60 years), participants with the highest intake of Mg had the lowest prevalence of high FBG[15]. In another study conducted in healthy young adults, prevalence of high FBG was approximately half in the lowest as compared with the highest quartile of Mg intake[5]. Some short-term clinical trials also provide support for a beneficial effect of Mg intake on glucose metabolism, but results have not been consistent[37]. Because Mg has a cofactor role for a number of relevant enzymes, low Mg status may directly regulate glucose metabolism; observational studies support these potential beneficial effects[38,39]. Several clinical trials also reported that increasing Mg intake leads to decreases in lipid concentrations[40]. The underlying mechanisms by which Mg intake influences TAG levels are still not well

Table 5 Multiple linear regression analysis of the association between dietary magnesium intake and metabolic syndrome outcomes according to age, gender and fibre intake categories: men and women aged 18–74 years, Tehran Lipid and Glucose Study

Outcome per unit increase in Mg intake (g/4184 kJ (1000 kcal))	Model 1*			Model 2*			Model 3*		
	β	95 % CI	P	β	95 % CI	P	β	95 % CI	P
Age									
Age ≤ 50 years (*n* 1846)	−0·090	−0·020, −0·001	0·03	−0·011	−0·023, −0·001	0·045	−0·015	−0·012, 0·002	0·06
Age > 50 years (*n* 658)	−0·12	−0·27, −0·03	<0·001	−0·14	−0·20, −0·03	<0·001	−0·11	−0·20, −0·03	<0·001
Gender									
Men (*n* 1120)	0·013	0·001, 0·004	0·083	0·023	−0·001, −0·002	0·48	0·025	−0·001, 0·002	0·49
Women (*n* 1384)	−0·110	−0·001, −0·003	0·072	−0·003	−0·001, 0·001	0·53	−0·018	−0·00, 0·001	0·57
Fibre intake†									
Low fibre (*n* 1299) (<32 g/d)	0·006	−0·006, 0·007	0·81	−0·006	−0·007, 0·005	0·81	−0·015	−0·006, 0·009	0·61
High fibre (*n* 1205) (<32 g/d)	−0·001	−0·002, −0·006	0·001	−0·003	−0·001, −0·005	0·001	−0·004	−0·005, −0·000	0·02

*Model 1, crude β; model 2, adjusted for age (except for age category), gender (except for gender category), smoking status and physical activity; model 3, adjusted as in model 2 plus total fibre intake (except for fibre intake category), SFA, Na, K, Ca, oestrogen use, menopausal status, fish and food groups.
†Participants were stratified into high and low fibre intake according to the median (32 g/d).

understood; increase in lipoprotein lipase activity, which is involved in the conversion of TAG to HDL-C, suggests a potential mechanism that explains associations between dietary Mg insufficiency or deficiency and risk of MetS[14].

In the present study, men and women with the highest Mg intakes were less likely to be abdominally obese than those with the lowest intakes. A higher Mg was associated with a lower prevalence of abdominal adiposity or central obesity in young adults aged 18–30 years[34] and in adults between the ages of 45 and 64 years[32], using WC to define abdominal adiposity based on the ATP III criteria[41]. In type 2 diabetes mellitus patients, low Mg status was associated with greater abdominal adiposity, as defined by WC[42]. The mechanisms through which Mg affects abdominal obesity are unclear but they may be related to its capability of forming soaps with fatty acids in the intestine, thus reducing the digestible energy content of the diet[43]. Furthermore, major foods contributing to Mg intake are whole grains[44], nuts[45], fruits and vegetables[34], all of which have inverse relationships with body weight. Inconsistencies between studies may be due to the intra-individual differences in food intake, not controlling for other covariates and excluding of under- and over-reporters.

In addition to Mg, many other components of foods including fibres, vitamin E, several B-vitamins and lignans may contribute to the beneficial effects of whole grains on components of MetS[46].

Considering that foods containing high Mg have high fibre, any investigations of the association between Mg and MetS should obviously take fibre intakes into account. The inverse association that we found between Mg intake and some MetS components could not explained by dietary fibre intake. Adjustment for fibre did not change the association of Mg with MetS and MetS components. However, Mg and fibre intakes were highly correlated, raising a concern about multicollinearity, which may be due to similarity in the foods including both fibre and Mg. Some studies suggest a more important role for foods with high content of fibre and Mg. In addition, the Mg content of vegetables is reduced following cooking, which could also explain our results. The important point is that most Iranians eat fried vegetables, consuming foods rich in Mg and fibre with oil.

Another point that should be considered is that associations between Mg and the risk of MetS are documented primarily in Western populations, among whom food sources of Mg differ from those in our population. For example, consumption of wholegrain foods is a good source of Mg in Western populations and has been associated with a significantly reduced risk of MetS; however rice, the main staple food in Iran, is highly refined and, in general, the consumption of wholegrain foods is limited.

Some clinical trials studying the effect of Mg on metabolic outcomes and diabetes reported only modest or inconsistent results, indicating an important role for other nutrients. It seems that diets have more beneficial effects rather than the single nutrient intake. These results are supported by those of clinical trials on antioxidant vitamins, implying that more favourable effects may be obtained from whole grains due to their higher Mg and fibre content[47].

In contrast to other studies, our study showed a modest association between dietary Mg intake and MetS Z-score. We attempted to adjust for some of the stronger lifestyle risk factors, such as physical activity, smoking and BMI. We cannot definitely conclude that these protective associations observed with higher Mg intake are due to the possibility of residual confounding or confounding by other healthy lifestyle characteristics. In line with our study, the protective effect of Mg intake was only seen in women with high BMI[11].

Some limitations should be considered when interpreting the findings of the current study. The cross-sectional design of our study precludes any causal inferences about the role of Mg. Second, the protective association of Mg with MetS cannot be independent of fibre, Ca and K, because good food sources of Mg including vegetables, nuts, dried beans, meats and whole grains are good sources of other nutrients as well. Third, we did not measure serum Mg level; although many studies have measured serum Mg level, a relatively minor compartment for Mg, the values may not reflect Mg levels in tissues[48].

In conclusion, our results indicate that dietary Mg intake may protect against MetS. Long-term intervention studies and longitudinal data are recommended to provide stronger evidence on this association.

Acknowledgements

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