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Prospective Study

Prospective study of total and various types of vegetables and the risk of metabolic syndrome among children and adolescents

Somayeh Hosseinpour-Niazi, Bahar Bakhshi, Ekbal Betru, Parvin Mirmiran, Mina Darand, Fereidoun Azizi

ORCID number: Somayeh Hosseinpour-Niazi (0000-0002-0210-6787); Bahar Bakhshi (0000-0003-3748-1429); Ekbal Betru (0000-0002-9059-1152); Parvin Mirmiran (0000-0003-2391-4924); Mina Darand (0000-0002-4830-472X); Fereidoun Azizi (0000-0003-3134-1441).

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Somayeh Hosseinpour-Niazi, Bahar Bakhshi, Ekbal Betru, Mina Darand, Nutrition and Endocrine Research center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran 19395-4763, Iran

Parvin Mirmiran, Department of Clinical Nutrition and Dietetics, Faculty of Nutrition Sciences and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran 19395-4763, Iran

Fereidoun Azizi, Endocrine Research Center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran 19395-4763, Iran

Corresponding author: Parvin Mirmiran, PhD, Associate Professor, Department of Clinical Nutrition and Dietetics, Faculty of Nutrition Sciences and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, No. 24, A'rabi St, Yeman Av, Velenjak, Tehran 19395-4763, Iran. mirmiran@endo-crime.ac.ir

Telephone: +98-21-22357484

Fax: +98-21-22416264

Abstract**BACKGROUND**

Data available on the association between consumption of various types of vegetables and metabolic syndrome (MetS) remain inconsistent.

AIM

To investigate the association between the intake of various types of vegetables and MetS among children and adolescents and MetS.

METHODS

The Tehran Lipid and Glucose Study cohort included 424 children and adolescents initially free of MetS. At the 3.6 year follow-up, 47 new cases of MetS were identified. A 168-item semi-quantitative food-frequency questionnaire was used to collect information about total and various types of vegetables consumed, including allium-, green leafy-, fruity-, root-, stalk-, starchy-, potatoes, and cabbage. MetS was defined according to the Cook *et al*^[32] criteria.

RESULTS

The median (interquartile range) of total vegetable consumption was 217 (146-344) g/d. After adjustment for demographic characteristics and dietary intake, higher total- (≥ 350 g/d) and higher allium vegetable consumption (≥ 30 g/d) in the fourth quartile were significantly and inversely associated with risk of MetS

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compared to the first quartile. Consumption of green leafy vegetables in the third (21.4-38.3 g/d) *versus* the first quartile (≤ 13.5 g/d) demonstrated a significant inverse association with lower risk of MetS in children and adolescents; associations for other types of vegetables consumed were not significant.

CONCLUSION

Consumption of vegetables, especially allium and green leafy vegetables, in sufficient amounts may be beneficial in reducing the risk of MetS among children and adolescents.

Key words: Metabolic syndrome; Children and adolescents; Vegetable; Allium; Green leafy vegetables

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Core tip: Data on the association between vegetable intake as an individual dietary component and metabolic syndrome (MetS) remain inconsistent. This inconsistency of findings may probably be due to a difference in the amounts and specific subgroups of vegetables in different studies. This prospective study of Iranian children and adolescents reported an inverse association between total vegetable consumption and MetS risk. Among vegetable subgroups, consumption of green leafy- and allium vegetables was inversely associated with risk of MetS after adjustment for the main potential confounders.

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INTRODUCTION

Metabolic syndrome (MetS) is characterized by the clustering of metabolic abnormalities such as glucose intolerance, central obesity, hypertension, and dyslipidemia. Although there is no concurrence on a MetS definition for children and adolescents, the prevalence of MetS in obese children is documented to be approximately 30%^[1]. Since MetS components show stability from childhood to adulthood, children fulfilling diagnostic criteria for MetS may remain at high risk as they enter adulthood^[2]. MetS severity in childhood has been linked to future risk of type 2 diabetes and cardiovascular disease (CVD)^[3], indicating that implementing interventions for a healthy lifestyle early in childhood might be preventive against future development of MetS and its complications.

The primary goal for MetS management is to alleviate all metabolic risk factors through effective lifestyle changes^[4]. Research indicates healthy dietary patterns, such as the Mediterranean and Dietary approach to stop hypertension diets, all of which recommend high intakes of vegetables, improve MetS and type 2 diabetes^[5,6]; however, data on the associations between vegetable intakes as an individual dietary component and MetS, type 2 diabetes, and CVD remain inconsistent^[7-13]. Although one meta-analysis, including 26 observational studies, reported beneficial effects for consumption of vegetables on MetS^[7], another meta-analysis of randomized controlled trials found no effect on MetS components^[8]. Protective effects of vegetable consumption against other nutrition-related chronic diseases, such as type 2 diabetes, are also still not clear; some report an inverse association^[9], while others document none^[10,11]. Some others report a threshold of around two-three servings/day of vegetables, after which diabetes risk did not reduce further^[12,13]. This inconsistency of findings might probably be due to differences in the amounts and specific subgroups of vegetables in different studies. Biological effects of vegetables may vary due to their phytochemical profiles: Leafy vegetables as a source of nitrogen containing compounds, nitrate, and carotenoids, lutein, polyphenols, flavonoids, phenolic acids, and lignans^[14]; Cabbage as a source of polyphenols, flavonoids, phenolic acids, lignans; Allium vegetables as source of organosulfur compound, allyl cysteine, alliin,

allicin, and allyl disulfide, flavonoids, and phenolic compounds^[15]; and fruity vegetables as a source of carotenoids, lycopene and pro-vitamin A, beta-carotene^[7]. In addition, consuming a variety of vegetables, such as green leafy-, allium-, and cruciferous vegetables, has been inconsistently associated with CVD risk^[16-21] and type 2 diabetes^[9,11,22,23].

As mentioned, subgroups of vegetables may differ in nutritional content, energy, fiber, and phytochemicals^[24]. Considering the limited data available on the association of different types of vegetables with MetS, the aim of our study was to investigate the association between intake of various types of vegetables and MetS after 3.6 years of follow-up in Tehranian children and adolescents, aged 6-18 years.

MATERIALS AND METHODS

Subjects and methods

This prospective population-based study was conducted within the framework of the Tehran lipid and glucose study (TLGS), an ongoing, prospective community based study, aimed at preventing non-communicable disease and reducing its risk factors through promoting healthy lifestyles. Detailed characteristics of the TLGS have been described elsewhere^[25]. Briefly, phase I of the TLGS was initiated in March 1999. A multistage cluster sampling was used to randomly select > 15000 individuals, aged ≥ 3 years from residents of Tehran's urban district 13, a group representing the urban population of Tehran. Follow-up data are collected every 3 years to update participants, data on demographics, lifestyle, biochemical, clinical, and dietary assessments. Phases II, III, and IV are prospective follow-up studies conducted between 2002-2005, 2006-2008, and 2009-2011, respectively. The current prospective population-based study was conducted during a mean 3.6 years of follow-up (follow-up rate: 86%); baseline data were obtained from phase III of TLGS (2006-2008), and outcome examination data were from phase IV (2009-2011).

For the current study, of 12523 individuals who entered survey III of TLGS, based on age and gender, 4920 subjects were randomly selected for collection of nutritional data. This sample size was chosen owing to the cost, complexity, and time involved in collection of dietary data in a large population. Characteristics of participants who had complete dietary data were similar to those of the total population in phase III of the TLGS^[26]. Of the 4920 participants enrolled in the present study, 621 children and adolescents, aged 6-18 years, agreed to complete the food frequency questionnaire (FFQ). Those who had missing data on dietary intakes or MetS components ($n = 29$), those who had baseline MetS ($n = 69$), and participants who over- or under-reported ($n = 122$) were all excluded. According to the equation proposed by the institute of medicine^[27], by dividing the reported energy intake by the estimated energy requirement (EER), individuals who were not within the ± 3 SD range (those in the top and bottom 1% of the energy intake to EER ratio), were defined as under and over-reporters. Finally data of 424 participants was used for analysis (response rate 68% during the 3.6 years follow-up). Anthropometric and biochemical measurements of participants who provided follow-up assessments was similar to those lost to follow-up.

The study protocol was approved by the ethics committee of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, and written informed consent was acquired from participants prior to their inclusion in the study.

Dietary assessment

Dietary intake information over the previous year was assessed using a 168-item, validated, semi-quantitative FFQ^[28]. Consumption frequency of each food item was documented on a daily, weekly, monthly basis, by a trained dietitian, during face to face interviews; portion sizes were reported in household measures and converted to gram using household measures^[29]. Percentages of carbohydrate, fat, and protein intake were calculated by multiplying the grams of consumption of each food by the content of carbohydrate, protein, and fat. The composition values were obtained from the US Department of Agriculture (USDA) Food Composition Table (FCT), as the Iranian FCT is incomplete (limited to only raw materials and a few nutrients). Vegetable consumption was assessed using 28 vegetables and reported as grams per day. General classification of our subgroups of vegetables (green leafy-, allium-, stalk-, fruity, root-, starchy-, cabbage, and potatoes) was based on Cooper *et al*^[9] and the classification used in the EPIC-InterAct study.

Reliability and validity of the FFQ for total vegetable consumption was acceptable (adjusted correlation coefficient between FFQ and multiple 24 recalls was 0.69 and 0.50, respectively; between the two FFQs it was 0.46 and 0.50 in males and females,

respectively)^[28]. Also, dietary patterns derived from the FFQ have shown reasonable reliability, validity, and stability over time^[30].

Biochemical measurement

Blood samples were drawn after 12-14 h of overnight fasting, between 7:00-9:00 a.m. from all participants, at baseline and follow-up. All blood analyses were done at the TLGS research laboratory on the day of sample collection. The enzymatic colorimetric method using glucose oxidase was used to measure fasting plasma glucose (FPG). High density lipoprotein cholesterol (HDL-C) was measured after precipitation of the apolipoprotein B-containing lipoproteins with phosphotungstic acid. Using the enzymatic colorimetric method with glycerol phosphate oxidase, triglycerides (TG) concentrations were measured. All analyses were performed using commercial kits (Pars Azmoon Inc., Tehran, Iran). Inter- and intra-assay coefficients of variations at baseline were both 2.2% for FPG, 2% and 0.5% for HDL-C, and 1.6% and 0.6% for TG, respectively.

Assessment of other variables

Blood pressure was measured manually twice using a standard mercury sphygmomanometer after a 15 min rest in supine position, and the mean of two measurements was considered as the participants' blood pressure. Height was measured without shoes using a stadiometer, while participants were standing with shoulders in normal alignment, and recorded to the nearest 0.1 cm. Weight was measured without shoes, with participants wearing light clothes, using a digital scale, and recorded to the nearest 0.1 kg (Seca 707; Seca Corporation, Hanover, MD, United States; range 0.1-150 kg). Body mass index (BMI) was calculated as weight (kg) divided by the square of height (m²). Waist circumference (WC) was measured at the midpoint between the iliac crest and lowest rib, recorded to 0.1 cm, in a standing position using an unstretched elastic tape. Physical activity level was calculated to metabolic equivalent task minutes per week, using the modifiable activity questionnaire, the high reliability (97%) and moderate validity (49%) of which have been verified previously for the Persian translated modifiable activity questionnaire in adolescents^[31]. Levels of physical activity were expressed as metabolic equivalent hours per week. Smoking history was collected using a questionnaire and categorized as smokers (smoked > 1 cigarette per day) and non-smoker/ex-smoker. Medical history and data on current use of medications, family history of diabetes, age, and gender were obtained using a questionnaire, as reported previously^[25].

Definition of MetS

Since there is no consensus regarding the criteria and definition of MetS for children and adolescents, the Cook *et al.*^[32] proposed definition, which defines MetS as ≥ 3 of the following criteria, was used: (1) TG ≥ 110 mg/dL or; (2) HDL-C < 40 mg/dL; (3) FPG ≥ 100 mg/dL, according to the recent recommendations of the American Diabetes Association^[33]; (4) Systolic blood pressure or diastolic blood pressure ≥ 90 th percentile for sex, age, and height, from the cut off points recommended by the National Heart, Lung, and Blood Institute^[34]; and (5) WC ≥ 90 th percentile for age and sex, according to national reference curves^[35]. Pre-MetS has been defined as having two components of these criteria^[36].

For individuals aged > 18 years after follow-up, MetS was defined as the presence of three or more of five components, as recommended by the Joint Interim Statement of the International Diabetes Federation as follows: (1) Low serum HDL cholesterol (< 40 mg/dL in men and < 50 mg/dL in women); (2) Abnormal glucose homeostasis (FPG ≥ 100 mg/dL or use of hyperglycemic medication); (3) Elevated blood pressure (systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 85 mmHg or use of antihypertensive medication); (4) High serum triglyceride concentration (≥ 150 mg/dL or use of antihypertriglyceridemia medication); and (5) Enlarged WC (≥ 95 cm according to the newly introduced cut-off points for Iranian adults for both genders)^[37,38].

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (v. 15.0; SPSS, Chicago, IL, United States), with statistical significance set at as $P < 0.05$. Consumption of total- and various types of vegetables was categorized into quartiles according to their baseline intakes. One-way analysis of variance and chi-squared test were used to report baseline characteristics and dietary intakes (adjusted for energy intakes) in total vegetable categories; data are presented as means \pm standard error and median [interquartile range (IQR)] for continuous variables, and percentages for categorical variables. Odds ratio (ORs) and 95% confidence intervals (CIs) of incident MetS were estimated across quartiles of total- and different types of vegetable consumption using

the logistic regression model, with the first quartile being used as a reference. Model 1 was crude. Model 2 was adjusted for age, gender, physical activity, family history of diabetes, total energy-, and cholesterol intake at baseline. Model 3 was additionally adjusted for BMI at baseline. Tests for trend of ORs across quartiles of total and various types of vegetables were conducted by assigning the median value to each quintile as a continuous variable in the regression models. By multivariable regression models, we further performed stratified analysis by categories of number of components of MetS (0, 1, or 2 components of Mets) at baseline to estimate ORs of MetS based intake of total and various types of vegetable consumption (above/below the medians).

RESULTS

Among 424 children and adolescents free of MetS at baseline, 47 (11%) were diagnosed with MetS during a median follow-up period of 3.6 years. Participants (58% girls) were aged 13.5 (SD 3.7) years at baseline with BMI 20.0 (SD 3.8) kg/m². Median \pm IQR of total vegetables consumption was 217 (146-344) g/d. At baseline, the median (IQR) from highest to lowest range of various types of vegetable consumption was: Fruity vegetables 115 (69.5-211.0), leafy vegetables 21.4 (13.4-38.4), allium vegetables 17.6 (6.3-30.5), potatoes 10.3 (4.8-20.7), root vegetables 9.9 (4.2-22.3), other starchy vegetables 5.8 (3.3-12.6), cabbage 3.1 (0.0-6.2), and stalk vegetables 0.45 (0.0-1.1).

Table 1 presents the characteristics of participants according to quartiles of total vegetable consumption. Participants in the highest quartile had low systolic blood pressure, low fasting blood glucose, and high HDL cholesterol concentrations at baseline. After 3.6 years of follow-up, FBS was significantly lower and HDL cholesterol significantly higher among those in the highest quartile of total vegetable consumption, compared with those in the lowest. No statistically significant associations were found for age, gender, physical activity levels, family history of diabetes, parental education level and occupational status, and BMI. The prevalence of subjects with 0, 1, and 2 components of MetS did not differ across quartiles of vegetable consumption. There was no significant difference in total vegetable consumption [median (IQR)] between participants with 0 [206 (145-322 g/d)], 1 [217 (144-351 g/d)], and 2 components of MetS [226 (161-345 g/d)] at baseline.

Table 2 presents energy adjusted means for dietary components across quartiles of total vegetable consumption. Participants who consumed more vegetables, also consumed more of types of vegetables. Consequently, those with a high intake of vegetables consumed more total fiber, cholesterol, magnesium, potassium, fruit, nuts, and dairy products.

Table 3 presents ORs of MetS associated with the total and various types of vegetables among children and adolescents. Compared to the first quartile, a higher consumption of total- (≥ 350 g/d) and allium (≥ 30 g/d) vegetables in the fourth quartile was significantly and inversely associated with risk of MetS in unadjusted model (model 1), the adjusted model for demographic characteristics and dietary intake (model 2), and BMI (model 3 in allium vegetables). Consumption of green leafy vegetables in the third (21.4-38.3 g/d) *versus* the first quartile (≤ 13.5 g/d) was significantly and inversely associated with risk of MetS in the unadjusted (model 1) and the model adjusted for demographic characteristics and dietary intakes (model 2); further adjustment for BMI attenuated these associations. Among vegetables, fruity-, root-, stalk-, starchy-, cabbage, and potatoes, were not associated with MetS among children and adolescents.

Table 4 presents ORs for MetS based intake of total and various types of vegetable consumption (above/below the medians) among participants with 0, 1, or 2 components of MetS at baseline. Among participants with 1 component of MetS, green leafy- and allium vegetables reduced the risk of MetS by 71% (0.23, 95%CI: 0.07-0.71) and 77% (0.29, 95%CI: 0.07-0.71), after adjustment for confounding factors. No association was found between total-, fruity-, root-, stalk-, starchy vegetables, cabbage, and potatoes and risk of MetS among participant with ≥ 2 components at baseline.

DISCUSSION

This prospective study of Iranian children and adolescents reported an inverse association between total vegetable consumption and MetS risk. Among vegetable subgroups, consumption of green leafy- and allium vegetables was inversely

Table 1 Baseline characteristics of participants by quartiles of total vegetable consumption: Tehran lipid and glucose study

	Quartiles of total vegetable consumption				P ¹ value
	1	2	3	4	
Participants, <i>n</i>	106	106	106	106	
Number of components of MetS at baseline, <i>n</i>					
No component	42	45	45	49	0.91
1 component	40	41	40	47	
2 components, pre-MetS	24	20	21	10	
Metabolic syndrome after 3.6 yr, <i>n</i>	17	12	10	8	
Age, yr	13.1 ± 0.3	13.3 ± 0.3	13.7 ± 0.3	13.9 ± 0.3	0.31
Female, %	53.8	65.1	54.7	56.6	0.32
Low physical activity, %	61	73	69	52	0.74
Family history of diabetes, %	4.7	8.5	3.8	3.8	0.37
BMI, kg/m ²	19.6 ± 0.4	20.7 ± 0.3	20.0 ± 0.3	19.8 ± 0.3	0.18
Parental academic degrees, %	25.2	26.9	22.8	25.2	0.48
Parental occupational status, employed, %	83.6	87.4	81.7	82.2	0.39
Systolic blood pressure, mmHg					
At baseline	99.1 ± 1.1	98.1 ± 1.1	96.2 ± 1.1	95.0 ± 1.1	0.04
After 3.6 yr	101 ± 1.2	100.2 ± 2	101.2 ± 1.2	98.8 ± 1.2	0.44
Diastolic Blood pressure, mmHg					
At baseline	65.1 ± 0.9	65.0 ± 0.9	63.9 ± 0.9	64.3 ± 0.9	0.76
After 3.6 yr	66.5 ± 0.9	68.4 ± 0.9	68.2 ± 0.9	69.0 ± 0.9	0.27
Fasting blood glucose, mg/dL					
At baseline	86.6 ± 0.6	84.3 ± 0.6	85.1 ± 0.6	84.2 ± 0.6	0.036
After 3.6 yr	91.8 ± 0.7	89.8 ± 0.7	89.3 ± 0.7	88.9 ± 0.7	0.037
Serum triglycerides, mg/dL					
At baseline	78.0 (60.0 - 95.0)	83.0 (63.0 - 100.0)	83.0 (64.0 - 103.0)	78.5 (64.0 - 105.0)	0.64
After 3.6 yr	79.0 (60.7 - 109.0)	73.0 (60.0 - 101.0)	74.0 (60.0 - 96.0)	77.0 (62.5 - 98.5)	0.58
Serum HDL-C, mg/dL					
At baseline	45.2 ± 1.1	44.8 ± 1.1	44.8 ± 1.1	48.5 ± 1.1	0.030
After 3.6 yr	50.5 ± 1.2	50.0 ± 1.2	51.3 ± 1.2	55.1 ± 1.2	0.014
Waist circumference, cm					
At baseline	67.3 ± 1.0	68.2 ± 1.0	69.5 ± 1.0	70.3 ± 1.0	0.16
After 3.6 yr	76.1 ± 1.0	77.0 ± 1.0	77.9 ± 1.0	77.6 ± 1.0	0.62

¹mean ± SE for all these values, except for variables was determined. Serum triglycerides reported as median (interquartile range). P values determined using ANOVA for continuous variables and chi-square test for categorical variables. BMI: Body mass index; MetS: Metabolic syndrome; HDL-C: High density lipoprotein cholesterol.

associated with risk of MetS after adjustment for the main potential confounders. In addition, we found that among participants with 1 component of MetS, consumption of allium- and green leafy vegetables reduce risk of Mets. However limited sample size in participants with 0 and 2 components of MetS may influence the association between consumption of vegetables and MetS.

Although the effects of vegetable intake on MetS have been investigated by numerous epidemiological and interventional studies, most findings remain inconclusive^[7,8]. Furthermore, in relation to type 2 diabetes, the efficacy of vegetable consumption is still not clear; some studies report inverse associations^[9], while others report none^[10,11]. Another documented a threshold of around two-three servings/day of vegetables, after which diabetes and CVD risk did not reduce further^[12,13,16]. In the current study, we found that consumption of vegetables, median intake of 440 g/wk, reduced risk of MetS by 60% among children and adolescents, findings consistent with dietary pattern studies in which healthy diets rich in vegetables are associated with a reduced risk of MetS and its components in children and adolescents^[39,40]. However, in a comprehensive systematic review of studies addressing fruit and vegetable consumption and cardiovascular risk indicators in adolescents, only one-third of the studies showed significant inverse associations of fruit and vegetable

Table 2 Baseline dietary intakes of participants by quartiles of total vegetable consumption: Tehran lipid and glucose study

	Quartiles of total vegetable consumption				P value
	1	2	3	4	
Fruity vegetables, g/d	57.5 ± 9.2	99.2 ± 9.2	156 ± 9.2	293 ± 9.2	< 0.001
Root vegetables, g/d	7.9 ± 1.9	14.8 ± 1.9	18.7 ± 1.9	27.3 ± 1.9	< 0.001
Stalk vegetables, g/d	0.7 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.7 ± 0.2	0.002
Leafy vegetables, g/d	19.1 ± 2.3	24.2 ± 2.3	30.8 ± 2.2	44.3 ± 2.4	< 0.001
Potatoes, g/d	9.7 ± 2.8	13.6 ± 2.7	17.7 ± 2.7	28.8 ± 2.9	< 0.001
Starchy vegetables, g/d	7.6 ± 1.3	8.2 ± 1.2	13.4 ± 1.2	11.3 ± 1.3	0.003
Cabbage, g/d	2.4 ± 1.5	5.1 ± 1.4	8.6 ± 1.4	12.8 ± 1.5	< 0.001
Allium vegetables, g/d	13.7 ± 2.4	18.0 ± 2.3	25.3 ± 2.3	41.4 ± 2.4	< 0.001
Total energy, Kcal/d	1981 ± 113	2171 ± 113	2703 ± 113	3383 ± 113	< 0.001
Carbohydrate, % of total energy	56.5 ± 0.7	56.7 ± 0.7	57.2 ± 0.7	57.3 ± 0.7	0.82
Protein, % of total energy	13.2 ± 0.2	12.8 ± 0.2	13.1 ± 0.2	13.4 ± 0.2	0.33
Fat, % of total energy	32.4 ± 0.7	32.5 ± 0.7	32.3 ± 0.7	32.1 ± 0.7	0.98
SFA, % of total energy	11.4 ± 0.3	11.1 ± 0.3	10.9 ± 0.3	11.1 ± 0.3	0.64
MUFA, % of total energy	11.2 ± 0.3	11.0 ± 0.3	11.2 ± 0.3	11.1 ± 0.3	0.92
PUFA, % of total energy	6.5 ± 0.2	6.6 ± 0.2	6.7 ± 0.2	6.5 ± 0.2	0.90
Total fiber, g/d	27.4 ± 2.4	30.5 ± 2.4	42.0 ± 2.4	49.6 ± 2.4	< 0.001
Cholesterol, g/d	190 ± 14	205 ± 14	267 ± 14	316 ± 14	< 0.001
Magnesium, mg/d	301 ± 20	324 ± 20	433 ± 20	547 ± 20	< 0.001
Potassium, mg/d	2835 ± 171	3127 ± 171	4228 ± 171	5588 ± 171	< 0.001
Whole grain, g/d	90 ± 16	92 ± 16	94 ± 16	92 ± 16	0.251
Refined grain, g/d	356 ± 26	354 ± 26	359 ± 26	351 ± 26	0.632
Fruit, g/d	272 ± 31.6	308 ± 31.6	453 ± 31.6	609 ± 31.6	< 0.001
Nuts	6.9 ± 1.4	7.9 ± 1.3	9.8 ± 1.3	14.5 ± 1.3	0.001
Legumes	11.9 ± 2.2	12.0 ± 2.2	13.9 ± 2.2	14.5 ± 2.2	0.879
Dairy products	146 ± 39.7	517 ± 39.7	609 ± 39.7	704 ± 39.7	0.005
Meat, poultry, fish, g/d	53.8 ± 10.1	56.1 ± 10.1	59.1 ± 10.1	52.7 ± 10.1	0.548

Data are mean and standard error, adjusted for energy intakes. SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.

intake and MetS and its components^[41]. This inconsistency may be because of differences in the amounts and specific subgroups of vegetables intake in different studies. More prospective and interventional studies are needed to specify the effects of various types of vegetables.

The association between green leafy vegetables and nutrition-related chronic disease was less consistent in prospective studies. In the “CHANCES” project, results from NIH-AARP and EPIC Elderly (All, Greece) cohorts reported consumption of green leafy vegetables is associated with a reduced [OR: 0.87 (0.84–0.90)] and increased [OR: 1.23 (1.01–1.50), OR: 1.52 (1.13–2.04)] risk of type 2 diabetes, respectively. The pooled analysis indicated no overall association between intake of green leafy vegetables, type 2 diabetes^[42], and CVD risk^[16]. Zhang *et al*^[7], in a meta-analysis of observational studies, concluded that consumption of green leafy vegetables might not be associated with MetS risk. Despite the results given above, several different meta-analyses suggest that green leafy vegetable consumption significantly reduced risk of type 2 diabetes and CVD^[9,11,16,18]; an increase of 0.2 serving/d of green leafy vegetables was associated with 13% reduction in type 2 diabetes^[23]. Our study showed that although consumption of green leafy vegetables significantly reduced risk of MetS to a median intake of 27 g/wk, there was a threshold of around 30 g/d, after which this inverse association disappeared; similar reductions of associated risk until the last median intake was similarly reported in two previous cohort studies^[22,23]. In the Women’s Health Study (median intake 0.92 serving/d), and the Shanghai Women’s Health Study (median intake 94.1 g/d), type 2 diabetes risk reduced up to the fourth quartile of intake but not further^[22,23]. Green leafy vegetables contain a maximum amount of nitrate, thus a risk-benefit effect of

Table 3 Multivariate adjusted odds ratio (95%CI) for metabolic syndrome across quartiles of total and various types of vegetable consumption: Tehran lipid and glucose study

	Quartiles of total- and various types of vegetable consumption				P value for Trend
	1	2	3	4	
Total vegetables					
Median intake, g/d	104	179	265	441	
Range of intake, g/d	≤ 146	147-217	218-343	≥ 350	
Model 1	1	0.66 (0.30-1.47)	0.54 (0.23-1.25)	0.42 (0.17-0.92)	0.06
Model 2	1	0.54 (0.21-1.46)	0.42 (0.16-1.07)	0.36 (0.14-0.94)	0.04
Model 3	1	0.53 (0.20-1.46)	0.41 (0.15-1.10)	0.35 (0.13-0.95)	0.04
Allium vegetables					
Median intake, g/d	2.7	10.8	22.8	51.5	
Range of intake, g/d	≤6.2	6.3-17.3	17.4-30.5	≥ 30.6	
Model 1	1	0.68 (0.31-1.47)	0.44 (0.19-1.05)	0.34 (0.13-0.87)	0.024
Model 2	1	0.55 (0.23-1.31)	0.27 (0.11-0.74)	0.21 (0.11-0.64)	0.006
Model 3	1	0.56 (0.24-1.32)	0.35 (0.13-0.89)	0.27 (0.14-0.75)	0.012
Green leafy vegetables					
Median intake, g/d	9.1	17.6	27.3	54.4	
Range of intake, g/d	≤13.5	13.6-21.3	21.4-38.3	≥ 38.4	
Model 1	1	0.42 (0.18-0.98)	0.32 (0.13- 0.80)	0.58 (0.26-1.27)	0.37
Model 2	1	0.40 (0.16-1.02)	0.32 (0.12-0.89)	0.81 (0.32-2.01)	0.98
Model 3	1	0.42 (0.16-1.11)	0.40 (0.13-0.91)	1.12 (0.39-3.19)	0.51
Fruity vegetables					
Median intake, g/d	42	93	145	263	
Range of intake, g/d	≤ 69	70-115	116-211	≥ 212	
Model 1	1	0.61 (0.25-1.47)	0.61 (0.25-1.47)	1.08 (0.49-2.37)	0.69
Model 2	1	0.65 (0.25-1.65)	0.64 (0.25-1.65)	1.01 (0.38-2.68)	0.34
Model 3	1	0.71 (0.27-1.87)	0.84 (0.32-2.23)	1.65 (0.57-4.80)	0.44
Root vegetables					
Median intake, g/d	2.1	7.3	10.0	34.4	
Range of intake, g/d	≤ 4.2	4.3-9.9	10.0-21.9	≥ 22.0	
Model 1	1	0.57 (0.20-1.64)	2.23 (0.99-5.03)	1.11 (0.45-2.74)	0.89
Model 2	1	0.72 (0.24-2.12)	1.74 (0.72-4.17)	1.13 (0.43-2.97)	0.87
Model 3	1	0.68 (0.22-2.07)	1.88 (0.75-4.72)	1.45 (0.50-4.13)	0.51
Stalk vegetables					
Median intake, g/d	0.0	0.2	1.0	2.5	
Range of intake, g/d	≤ 0.00	0.1-0.5	0.6-1.1	≥ 1.2	
Model 1	1	0.57 (0.24-1.36)	0.54 (0.23-1.29)	0.88 (0.40-1.94)	0.86
Model 2	1	0.52 (0.20-1.36)	0.51 (0.20-1.31)	1.09 (0.46-2.58)	0.51
Model 3	1	0.61 (0.23-1.62)	0.57 (0.21-1.51)	1.32 (0.52-3.34)	0.34
Potatoes					
Median intake, g/d	2.4	10.3	20.7	36.3	
Range of intake, g/d	≤4.8	4.9-10.4	10.5-20.8	≥ 20.9	
Model 1	1	0.69 (0.32-1.50)	0.97 (0.41- 2.28)	0.80 (0.32-1.99)	0.84
Model 2	1	0.54 (0.23- 1.27)	0.86 (0.34-2.21)	0.68 (0.25-1.85)	0.72
Model 3	1	0.58 (0.23-1.44)	1.03 (0.38- 2.76)	0.55 (0.17-1.68)	0.54
Starchy vegetables					
Median intake, g/d	1.9	4.7	8.2	18.2	
Range of intake, g/d	≤ 3.3	3.4-5.8	5.-12.6	≥ 12.7	
Model 1	1	0.91 (0.39-2.11)	1.0 (0.44-2.27)	0.66 (0.27-1.62)	0.36
Model 2	1	0.92 (0.37-2.31)	0.93 (0.38-2.26)	0.60 (0.22-1.62)	0.29
Model 3	1	0.99 (0.38-2.56)	0.80 (0.30-2.13)	0.80 (0.26-2.45)	0.41
Cabbage					

Median intake, g/d	0.0	1.9	6.2	15.3	
Range of intake, g/d	≤ 0.0	0.1 – 3.1	3.2-6.2	≥ 6.3	
Model 1	1	0.74 (0.36-1.52)	1.12 (0.40-3.14)	0.54 (0.21-1.38)	0.18
Model 2	1	0.79 (0.36-1.71)	1.25 (0.42-3.79)	0.51 (0.18-1.45)	0.07
Model 3	1	0.94 (0.42-2.10)	1.50 (0.48-4.69)	0.56 (0.18-1.71)	0.09

¹The median intake of each quartile category was assigned, and these quartile median variables were included as a continuous variable in logistic regression. Model 1 was crude. Model 2 was adjusted for age at baseline, gender, physical activity at baseline, family history of diabetes, total energy intake at baseline, and cholesterol intake at baseline. Model 3 was additionally adjusted for body mass index at baseline. CI: Confidence interval.

nitrate should be considered. The adequate intake for nitrate (3.7 mg/kg body weight/day equivalent to 222 mg nitrate per day for a 60 kg adult) is constantly exceeded in several dietary patterns. This overconsumption of dietary nitrate could hence be responsible for the disappearance of an inverse association between green leafy vegetable intake and MetS and the risk of type 2 diabetes after the third quartile of intake in our study and those of others^[43].

In the current study, allium vegetables were inversely associated with risk for MetS among children and adolescents. Positive effects of *A. sativum* on control of MetS and its components, especially dyslipidemia and diabetes, have been reported previously^[44]. Moreover, several prospective studies have been conducted regarding the positive effect of allium vegetables on CVD outcomes, chronic kidney disease, hypertension, ischemic heart disease mortality, cerebral vascular disease mortality, and myocardial infarction^[17,19,20] but not all^[21,45]. Allium is a rich source of phytonutrients, including organosulfur and phenolic compounds; their consumption two to three times per day improves the cardio-metabolic risk factors among individuals with diabetes and MetS, reduces inflammation and oxidative stress, and has a vasodilator effect^[46-49].

Few studies have investigated the association between cruciferous vegetables and MetS risk, and most of these report that dietary patterns rich in vegetables, including cruciferous, reduce the occurrence of MetS^[50,51]. Although our findings and also those of some previous studies found no protective effects of cruciferous vegetables^[21,45], others have reported a potential reduction in the risk of ischemic heart disease mortality, coronary heart disease, and subclinical atherosclerosis, which may be due to the lower amount of cruciferous vegetable intake in our study compared to others^[16,17].

In the current study, no association between fruity-, root-, stalk-, starchy vegetables, and potatoes and MetS was found. Results of research on the consumption of these vegetables and the risk of MetS is controversial, which may be due to the differences in the amounts and preparation methods used in these studies^[16,17,21,23,45,52-55]. Further investigations of various types of vegetable (*e.g.*, fruity-, starchy-, and root vegetables) consumption on MetS are needed.

Strengths and limitations

Major strengths of this study include the population-based prospective design of the study, participants of which were representative of Tehran's population, the large sample size, and use of a valid and reliable FFQ administered by a trained nutritionist (reducing any potential measurement errors), and the minimized loss to follow-up bias (response rate 86%). Nevertheless, the present study has a few limitations. First, MetS is heterogeneous; despite carefully adjusting for a range of known confounding factors, other factors associated with MetS among children and adolescents, including heredity and puberty status, were not addressed because of a lack of information. In addition, regarding the different types of vegetables (other than allium and green leafy vegetables) included in the analysis of this study, the failure to detect associations between consumption of these types of vegetables and MetS may be due to the narrow range of dietary intake among our participants.

In conclusion, findings of this prospective study indicate that consumption of green leafy vegetables and allium vegetables were associated with lower risk of MetS during 3 years of follow-up in children and adolescents.

Table 4 Multivariable odds ratio (95%CI) for metabolic syndrome based intake of total and various types of vegetable consumption (above/below the medians) among participants with 0, 1, or 2 components of metabolic syndrome at baseline: Tehran lipid and glucose study

	Model 1		Model 2		Model 3	
	< median	≥ median	< median	≥ median	< median	≥ median
Total vegetables, g/d						
0 component	1	0.48 (0.12-1.94)	1	0.77 (0.14-4.05)	1	0.82 (0.15-4.29)
1 component	1	0.68 (0.27-1.71)	1	0.62 (0.21-1.83)	1	0.67 (0.23-1.99)
2 component	1	1.98 (0.61-6.42)	1	2.00 (0.49-8.18)	1	2.24 (0.53-9.39)
Allium vegetables						
0 component	1	0.77 (0.21-2.85)	1	0.69 (0.17-2.76)	1	0.54 (0.12-2.42)
1 component	1	0.25 (0.08-0.73)	1	0.25 (0.08-0.76)	1	0.23 (0.07-0.71)
2 component	1	0.49 (0.16-1.52)	1	0.51 (0.15-1.78)	1	0.48 (0.13-1.69)
Green leafy vegetables						
0 component	1	0.81 (0.22-2.98)	1	1.04 (0.25-4.26)	1	1.10 (0.25-4.72)
1 component	1	0.31 (0.11-0.84)	1	0.31 (0.09-0.97)	1	0.29 (0.09-0.95)
2 component	1	1.01 (0.33-3.08)	1	1.43 (0.39-5.18)	1	1.39 (0.38-5.06)
Fruity vegetables						
0 component	1	1.13 (0.31-4.07)	1	1.15 (0.28-4.71)	1	0.88 (0.20-3.84)
1 component	1	0.66 (0.26-1.67)	1	0.60 (0.21-1.69)	1	0.64 (0.22-1.82)
2 component	1	1.51 (0.48-4.67)	1	2.02 (0.52-7.87)	1	2.11 (0.53-8.32)
Root vegetables						
0 component	1	2.36 (0.59-9.43)	1	2.57 (0.58-11.3)	1	2.31 (0.49-10.7)
1 component	1	2.20 (0.84-5.76)	1	1.68 (0.61-4.75)	1	1.67 (0.58-4.73)
2 component	1	1.97 (0.63-6.14)	1	1.48 (0.43-5.08)	1	1.31 (0.36-4.69)
Stalk vegetables						
0 component	1	1.28 (0.35-4.72)	1	1.33 (0.33-5.30)	1	1.08 (0.26-4.52)
1 component	1	0.72 (0.28-1.81)	1	0.73 (0.27-2.00)	1	0.74 (0.27-2.02)
2 component	1	1.18 (0.39-3.58)	1	1.09 (0.32-3.76)	1	1.13 (0.32-3.97)
Potatoes						
0 component	1	1.36 (0.34-5.45)	1	1.97 (0.39-9.90)	1	2.12 (0.39-11.4)
1 component	1	0.56 (0.22-1.42)	1	0.45 (0.17-1.22)	1	0.45 (0.16-1.24)
2 component	1	1.91 (0.55-6.66)	1	1.35 (0.34-5.39)	1	1.55 (0.36-6.65)
Starchy vegetables						
0 component	1	0.64 (0.17-2.36)	1	0.92 (0.21-3.90)	1	1.06 (0.24-4.60)
1 component	1	0.78 (0.31-1.96)	1	0.80 (0.29-2.18)	1	0.84 (0.30-2.32)
2 component	1	1.08 (0.35-3.30)	1	0.57 (0.15-2.11)	1	0.56 (0.15-2.14)
Cabbage						
0 component	1	0.64 (0.13-3.12)	1	0.88 (0.16-4.92)	1	0.89 (0.15-5.08)
1 component	1	1.19 (0.46-3.07)	1	1.64 (0.59-4.59)	1	1.54 (0.55-4.32)
2 component	1	0.48 (0.12-1.91)	1	0.53 (0.18-2.43)	1	0.45 (0.09-2.22)

Median intake of: Model 1 was crude; Model 2 was adjusted for, age at baseline, gender, physical activity at baseline, family history of diabetes, total energy intake at baseline, and cholesterol intake at baseline; Model 3 was additionally adjusted for body mass index at baseline. CI: Confidence interval.

ARTICLE HIGHLIGHTS

Research background

Metabolic syndrome (MetS) is characterized by the clustering of metabolic abnormalities, such as glucose intolerance, central obesity, hypertension, and dyslipidemia. The primary goal for MetS management is to alleviate all metabolic risk factors through effective lifestyle changes. Research indicates healthy dietary patterns, such as the Mediterranean and Dietary approach to stop hypertension diets, all of which recommend high intakes of vegetables, improve MetS and type 2 diabetes; however, data on the associations between vegetable intake as an individual dietary component and MetS remain inconsistent.

Research motivation

This inconsistency of findings between chronic disease such as MetS and vegetable consumption might probably be due to differences in specific subgroups of vegetables in different studies. Various types of vegetables differ in nutritional content, energy, fiber, and phytochemicals.

Research objectives

The aim of our study was to investigate the association between intake of various types of vegetables and MetS after 3.6 years of follow-up in Tehranian children and adolescents, aged 6-18 years.

Research methods

This prospective population-based study was conducted within the framework of the Tehran lipid and glucose study, an ongoing, prospective community based study, aimed at preventing non-communicable disease and reducing its risk factors through promoting healthy lifestyles. Of the 4920 participants enrolled in the present study, 621 children and adolescents, aged 6-18 years agreed to complete the food frequency questionnaire. Those who had missing data on dietary intake or MetS components, those who had baseline MetS, and participants who over- or under-reported, were all excluded. Finally, data of 424 participants were used for analysis. Dietary intake information over the previous year was assessed using a 168-item, validated, semi-quantitative food frequency questionnaire. Vegetable consumption was assessed using 28 vegetables and reported as grams per day. General classification of our subgroups of vegetables (green leafy-, allium-, stalk-, fruity-, root-, starchy-, cabbage, and potatoes) was based on EPIC-InterAct study. Blood samples were drawn after 12-14 h of overnight fasting and glucose, triglyceride and HDL-C concentrations were measured. Blood pressure and waist circumference were assessed using standard tools. MetS was defined using Cool *et al* criteria for individual <18 year. For participant aged ≥ 18 years, Joint Interim Statement of the International Diabetes Federation criterial was used to define the MetS.

Research results

Among 424 children and adolescents free of MetS at baseline, 47 (11%) were diagnosed with MetS during a median follow-up period of 3.6 years. Higher consumption of total- (≥ 350 g/d) and allium (≥ 30 g/d) vegetables were significantly and inversely associated with risk of MetS after adjustment for confounding factors. Consumption of green leafy vegetables in the third (21.4-38.3 g/d) *versus* the first quartile (≤ 13.5 g/d) was significantly and inversely associated with risk of MetS in the unadjusted (model 1) and the model adjusted for demographic characteristics and dietary intakes (model 2); further adjustment for BMI attenuated these associations. Among vegetables, fruity-, root-, stalk-, starchy-, cabbage, and potatoes were not associated with MetS among children and adolescents.

Research conclusions

Consumption of green leafy vegetables and allium vegetables were associated with lower risk of MetS during 3 years of follow-up in children and adolescents.

Research perspectives

Future studies addressing the underlying mechanisms of allium and green leafy vegetables in reducing the risk of MetS are needed.

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