Lifestyle Behaviors Associated With Lower Risk of Having the Metabolic Syndrome

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The metabolic syndrome is a cluster of risk factors that predisposes individuals to cardiovascular disease (CVD) and diabetes and is present in almost one fourth of adult Americans. Risk factors involved with the metabolic syndrome can be altered via modifiable lifestyle factors, such as diet, physical activity, and smoking and drinking habits. The objective of this study was to examine the extent to which these modifiable lifestyle behaviors are associated with the risk of having the metabolic syndrome. Data from the Third National Health and Nutrition Examination Survey (NHANES III), conducted between 1988 and 1994, were used to measure the risk of having the metabolic syndrome in healthy adult Americans who follow certain lifestyle behaviors, such as dietary practices, levels of physical activity, smoking and drinking habits. Low physical activity level, high carbohydrate (CHO) intake, and current smoking habits were all significantly associated with an increased risk of having the metabolic syndrome, even after adjusting for other related covariates. Relative to physically inactive subjects, being physically active was associated with lower odds ratio (OR) (0.36, confidence interval [CI] 0.21 to 0.68, $P < .01$) in overweight men and in normal weight (0.36, CI 0.18 to 0.70, $P < .01$) and overweight (0.61, CI 0.38 to 0.97, $P < .05$) women. Although the type of CHO could not be distinguished, relative to a high CHO diet, men having a low or moderate CHO intake had a lower risk of having the metabolic syndrome with respective ORs of 0.41 (CI 0.24 to 0.67, $P < .01$) and 0.44 (CI 0.25 to 0.77, $P < .01$); no effect of dietary CHO was observed in women. Moderate alcohol consumption was not significantly related to the risk of having the metabolic syndrome in men, but was associated with a lower OR in women (0.76, CI 0.61 to 0.95, $P < .05$). Regression models indicate a reduced risk of having the metabolic syndrome when selected low-risk lifestyle factors are present in combination, particularly in subjects with body mass index (BMI) < 30 kg/m^2. According to our cross-sectional logistic models, the risk of having the metabolic syndrome is substantially lower in individuals who are physically active, nonsmoking, have a relatively low CHO intake and moderate alcohol consumption, and who maintain a BMI in the non-obese range. These observations have potentially important value for public health recommendations.

THE METABOLIC SYNDROME is associated with an increased risk of developing cardiovascular disease (CVD) and appears in individuals as a cluster of risk factors that have sensitivity to the cellular actions of insulin in common.[1,2] The main components of the metabolic syndrome, including waist circumference, plasma glucose and lipid levels, and blood pressure, are all associated with excess adiposity, and weight loss is the primary therapeutic and preventive measure.[1,3]

A recent report based on a representative sample of the American population suggests that the metabolic syndrome criteria are met by approximately 1 in 4 adults.[4] Major efforts are now under way to detect and treat the metabolic syndrome as a means of lowering the risk of or preventing CVD in the US population.[1] Some behaviors or lifestyle patterns are associated with the metabolic syndrome and include physical activity, cigarette smoking, and diet, particularly carbohydrate (CHO) and fat intakes.[5-11] Our previous study examined the relationships of these factors with the metabolic syndrome,[12] however, the probability of having the metabolic syndrome in individuals within different body mass index (BMI) categories and the probability of having the metabolic syndrome in individuals who have a combination of these risk factors remains unknown.

Accordingly, in the present study, we used cross-sectional data to examine how different levels of each recognized lifestyle factor, or combinations of these lifestyle factors, impact on the risk of having the metabolic syndrome.

SUBJECTS AND METHODS

Subjects

Subjects over the age of 20 years from 4 ethnic groups, non-Hispanic blacks, Mexican Americans, non-Hispanic whites, and others were eligible for inclusion in the study. Among 18,825 eligible subjects, 5,904 subjects were excluded for lack of anthropometric, demographic, socioeconomic, or physical examination information, and 1,480 subjects were excluded due to improper fasting, defined as drinking or eating 6 hours before blood collection. In addition, 202 women who were pregnant or breast-feeding were also excluded. Therefore, 11,239 subjects, 5,415 men (48.2%) and 5,824 women (51.8%), were included in the analysis.

Study Design

The relationships between metabolic syndrome risk and lifestyle-related factors were modeled using data from a representative US sample, the Third National Health and Nutrition Examination Survey (NHANES III). This survey, conducted between 1988 and 1994 in 81 counties across the United States, includes 40,000 individuals over the age of 2 months who were not institutionalized during the evaluation period.[13]

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The NHANES III study used stratified, multistage probability cluster sampling and results from each respondent were weighted using a factor indicating sampling probability. The derived estimates of metabolic syndrome risk are thus representative of the entire American civilian population.[13]

The NHANES III database includes information on socioeconomic status, physical activity, dietary, and smoking habits, as well as anthropometric and biochemical data that can be used to assess the prevalence of the metabolic syndrome. These data were used to model the associations between the risk of having the metabolic syndrome and lifestyle-related behaviors, such as diet, physical activity, and smoking habits. These logistic models then allowed us to examine how variation in each specific lifestyle factor, controlling for other covariates, impacted on the risk of having the metabolic syndrome. Our models also allowed us to explore to what extent the effects of a combination of several low-risk behaviors impact on the risk of having the metabolic syndrome.

Definitions

Metabolic syndrome. Metabolic syndrome was defined according to the Third Report of the National Cholesterol Education Program expert panel on the detection, evaluation, and treatment of high blood cholesterol in adults (NCEP ATP III) criteria, which require that 3 or more of the following risk factors be present to establish the diagnosis of the metabolic syndrome[1]: abdominal obesity (waist circumference $>$ 102 cm in men and $>$88 cm in women); triglyceride levels $\geq$ 1.70 mmol/L [150 mg/dL]; high-density lipoprotein (HDL) cholesterol levels $<$ 1.04 mmol/L [40 mg/dL] for men or $<$1.30 mmol/L [50 mg/dL] for women; high blood pressure (systolic $\geq$ 130 mm Hg or diastolic $\geq$ 85 mm Hg); and fasting plasma glucose $\geq$ 6.11 mmol/L [110 mg/dL]. Subjects using blood pressure medication or oral hypoglycemic agents at the time of survey were considered as having the associated abnormal risk factor.

Socioeconomic factors. Subjects were divided into 3 groups according to completed years of schooling: $\leq$8 years, 9 to 12 years, and $>$12 years. Three economic status groups were also created according to the subject's household income for the previous year: $\leq$\$15,000, \$15,001 to \$25,000, and $>$\$25,000. Menopause was established in women at the time of interview as cessation of menstruation.

Lifestyle-related factors. Physical activity, CHO, fat, and alcohol consumption, as well as smoking habits, were chosen as lifestyle-related factors that may be modifiable and associated with the metabolic syndrome, while age, ethnicity, education, and household income levels were taken as fixed demographic characteristics of the subjects.

Physical activity intensity score was defined as the ratio of work metabolic rate to resting metabolic rate obtained by a history of participating in 1 of the following activities during the past month: walking, jogging or running, bicycle riding, swimming, lifting weights, or doing aerobics or aerobic dancing, other dancing, calisthenics, or garden/yard work.[13] Physical activity level was categorized based on the subject's physical activity intensity rating scores: being physically inactive referred to a physical activity intensity score of $\leq$3.5; being moderately active and active corresponded to intensity rating scores of 3.6 to 14.9 and $\geq$15.0, respectively, for both men and women.[12] These cutoff points were chosen to represent the 15th and 65th percentile of physical activity for males and 25th and 75th percentile for females.

Cutoffs used to categorize CHO and fat consumption reflected current dietary recommendations by the US Department of Health and Human Services: low, moderate, and high CHO intakes corresponded to $<$40%, 40% to 60%, and $>$60% of dietary energy intake; and low, moderate, and high fat intakes corresponded to $<$30%, 30% to 40%, $>$40% of dietary energy intake.[14]

Smoking was categorized as current, past, and never smoked. Past smokers were those who reported that they had smoked at least 100 cigarettes during their lifetime, but who did not currently smoke.

Drinking was categorized as heavy, light-to-moderate, and nondrinking. According to the recommendation by the US Department of Agriculture and Department of Health and Human Services, heavy drinkers were subjects who answered that they "ever drank 5 or more alcoholic beverages almost every day" or drank beer, wine, or hard liquor more than twice a day during the past month for men and once a day for women. Light-to-moderate drinkers had $\leq$2 alcoholic beverages per day during the past month for men or $\leq$1 drink per day for women.[15] Nondrinkers were those who did not drink any alcoholic beverage during the past month.

Each of the lifestyle factors was graded relative to an arbitrarily defined low-risk category according to their respective relationships with the metabolic syndrome. Five low-risk categories were defined during our analyses that included the following: normal weight (BMI $<$ 25 kg/m^2) or non-obese (BMI $<$ 30 kg/m^2); physically active; low or moderate CHO consumption; a history of never smoking; and a light-to-moderate alcohol intake.

Statistical Methods

The differences in baseline characteristics, expressed in the text as the mean and 95% confidence interval (CI), between men and women were tested using the adjusted Wald test. Statistical significance was set at $P < .05$. Stata (Version 7.0 for Windows, Stata, College Station, TX) was used to incorporate the complex sampling design of NHANES III to produce nationally representative estimates.

The first stage of analysis focused on identifying and modeling factors that confer a risk of the metabolic syndrome. Three logistic regression models were used to estimate the sex-specific metabolic syndrome odds ratio (OR) for lifestyle-related factors. In model 1, the independent variable was the specific lifestyle factor examined. This model tested the univariate relationship of the lifestyle factor with the metabolic syndrome. In model 2, age, ethnicity, education, household income, and menopausal status for women, were added into model 1 as covariates to test whether the relationship observed in model 1 changed after controlling for demographic characteristics. In model 3, all other lifestyle-related factors were incorporated into model 2 as additional covariates to verify whether these other lifestyle-related factors modified the association between the lifestyle factor examined and the metabolic syndrome.

To test the adequacy of the final model (model 3), we entered an additional variable that might plausibly be related to the dependent variable, such as total caloric intake, to determine whether this made significant contributions to the model.[16] In addition, we pooled men and women together to test the interaction between gender and lifestyle factor using regression model 3 to determine whether the association between lifestyle factors and metabolic syndrome differed between men and women.

In the second phase of the analysis, we explored the effects of a combination of several low-risk factors on the risk of having the metabolic syndrome. In condition 1, the odds of cases in the low-risk groups were compared with the odds of the remaining cases after controlling for age, ethnicity, education and income levels, menopausal status for women, and other lifestyle-related factors that were not involved in the low-risk groups. In conditions 2 and 3, BMI $<$ 30 and $<$25 kg/m^2 were, respectively, considered as additional factors to redefine the low-risk groups. These models provided an estimate of the odds of having the metabolic syndrome when specific low-risk lifestyle factors are present in general (condition 1) or when they are present in non-obese (ie, BMI $<$ 30 kg/m^2) or normal weight (ie, BMI $<$ 25 kg/m^2) subjects. The

Table 1. Metabolic Syndrome ORs According to Physical Activity Level

		All		<25		25-29.9		≥30	
BMI* (kg/m²)	Physical Activity	OR† (CI)‡	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value
Men									
Model 1	Active	0.41 (0.31-0.54)	<.001	0.61 (0.28-1.34)	.212	0.27 (0.18-0.40)	<.001	0.55 (0.31-0.97)	<.05
	Moderately active	0.91 (0.73-1.14)	.421	1.01 (0.53-1.94)	.969	0.66 (0.48-0.89)	<.01	1.08 (0.69-1.71)	.727
	Inactive (reference)	1.00		1.00		1.00		1.00	
Model 2	Active	0.54 (0.36-0.80)	<.01	0.99 (0.42-2.32)	.974	0.35 (0.20-0.63)	<.01	0.64 (0.36-1.13)	.122
	Moderately active	0.76 (0.56-1.04)	.086	0.95 (0.46-1.97)	.882	0.57 (0.38-0.85)	<.01	1.09 (0.68-1.75)	.721
	Inactive	1.00		1.00		1.00		1.00	
Model 3	Active	0.58 (0.39-0.85)	<.01	1.09 (0.48-2.50)	.831	0.36 (0.21-0.68)	<.01	0.67 (0.39-1.17)	.151
	Moderately active	0.79 (0.58-1.08)	.138	0.99 (0.50-1.97)	.973	0.58 (0.39-0.88)	<.05	1.11 (0.66-1.85)	.689
	Inactive (reference)	1.00		1.00		1.00		1.00	
Women									
Model 1	Active	0.25 (0.18-0.37)	<.001	0.10 (0.05-0.23)	<.001	0.32 (0.21-0.51)	<.001	0.69 (0.34-1.39)	.286
	Moderately active	0.69 (0.56-0.84)	<.01	0.77 (0.51-1.17)	.212	0.69 (0.48-0.99)	<.05	0.81 (0.63-1.05)	.106
	Inactive (reference)	1.00		1.00		1.00		1.00	
Model 2	Active	0.70 (0.48-1.01)	.057	0.32 (0.17-0.62)	<.01	0.56 (0.37-0.85)	<.01	0.80 (0.38-1.68)	.537
	Moderately active	0.85 (0.69-1.04)	.105	0.94 (0.64-1.37)	.738	0.73 (0.48-1.12)	.143	0.78 (0.63-0.97)	<.05
	Inactive (reference)	1.00		1.00		1.00		1.00	
Model 3	Active	0.76 (0.51-1.13)	.164	0.36 (0.18-0.70)	<.01	0.61 (0.38-0.97)	<.05	0.82 (0.38-1.79)	.611
	Moderately active	0.88 (0.72-1.08)	.214	1.01 (0.69-1.47)	.978	0.77 (0.50-1.17)	.209	0.79 (0.64-0.99)	<.05
	Inactive (reference)	1.00		1.00		1.00		1.00	

NOTE. Model 1 includes as a predictor only for specific lifestyle-related risk factor; model 2 adds age, race, education and income levels, and menopausal for women as predictors; and model 3 includes model 2 and other modifiable factors.

*BMI represents body-mass index; in the ALL group, the model was also adjusted for BMI as a continuous variable.

†ORs represent the metabolic syndrome odds ratios for modifiable lifestyle factors.

‡CI represents 95% confidence interval, ORs ± 1.96 SE.

regression models for low-risk groups evaluated in condition 1 were additionally adjusted for BMI.

RESULTS

Subject Characteristics

Women in the sample were significantly ($P < .001$) older (45.6 years; CI, 44.5 to 46.7) than men (43.8 years; CI, 43.0 to 44.6). Men had a significantly higher ($P < .05$) BMI (26.7 kg/m^2; CI, 26.5 to 26.9) than women (26.4 kg/m^2; CI, 26.3 to 26.6).

The overall prevalence of the metabolic syndrome was greater ($P < .05$) in men (23.0%) than in women (21.9%). The prevalence of the metabolic syndrome in men increased from 5.3% in the normal weight group to 21.9% and 58.8% in the overweight and obese groups, respectively. Similar results were observed in women, with the prevalence of the metabolic syndrome increasing from 5.5% to 27.5% and 48.8% when going from normal weight to overweight and obese groups, respectively.

Physical Activity and Risk

The ORs for being diagnosed with the metabolic syndrome as a function of physical activity level are organized according to sex and BMI in Table 1. The metabolic syndrome ORs were lower with greater levels of physical activity in men in all 3 regression models. When stratified by BMI, the risk of having the metabolic syndrome was significantly lower in physically active men compared with inactive men only in the overweight group (model 3, OR = 0.36; CI, 0.21 to 0.68; $P < .01$). The risk of having the metabolic syndrome in moderately active men was also lower in the overweight group (model 3, OR = 0.58; CI, 0.39 to 0.88; $P < .05$). In obese men, the ORs of having the metabolic syndrome were lower with greater levels of physical activity in the univariate regression model (model 1, OR = 0.55; CI, 0.31 to 0.97; $P < .05$), although the ORs became nonsignificant after adjusting for covariates in models 2 and 3.

Physical activity in women overall was not significantly associated with the risk of having the metabolic syndrome in models 2 and 3. In normal weight and overweight women, being physically active was associated with a lower risk of having the metabolic syndrome (OR = 0.36; CI, 0.18 to 0.70; $P < .01$ for normal weight and OR = 0.61; CI, 0.38 to 0.97; $P < .05$ for overweight women) compared with being inactive. In obese women, moderate physical activity was associated with a 21% lower risk of having the metabolic syndrome compared with inactivity (model 3, OR = 0.79; CI, 0.64 to 0.99; $P < .05$).

CHO Intake and Risk

The relationships between dietary CHO intake and the risk of being diagnosed with metabolic syndrome across sex and BMI categories are shown in Table 2. Overall, a low or moderate CHO intake, compared with a high CHO intake, was associated with a ≥50% lower OR of having the metabolic syndrome in men. In normal weight men, compared with a high CHO intake, a low CHO intake was associated with a significantly lower risk of having the metabolic syndrome in model 1; this was not significant after adjusting for covariates in models 2 and 3. A moderate dietary CHO

Table 2. Metabolic Syndrome ORs for Carbohydrate Intake

BMI* (kg/m²)	Carbohydrate Intake	All OR† (CI)‡	All *P* Value	<25 OR (CI)	<25 *P* Value	25-29.9 OR (CI)	25-29.9 *P* Value	≥30 OR (CI)	≥30 *P* Value
Men									
Model 1	Low	0.69 (0.50-0.98)	<.05	0.34 (0.14-0.76)	<.05	0.50 (0.29-0.86)	<.05	0.79 (0.37-1.65)	.514
	Moderate	0.65 (0.46-0.92)	<.05	0.40 (0.24-0.68)	<.01	0.59 (0.35-0.98)	<.05	0.71 (0.35-1.43)	.323
	High (reference)	1.00		1.00		1.00		1.00	
Model 2	Low	0.57 (0.39-0.84)	<.01	0.47 (0.20-1.10)	.81	0.53 (0.29-0.97)	<.05	0.80 (0.41-1.55)	.495
	Moderate	0.57 (0.38-0.86)	<.01	0.53 (0.32-0.86)	<.05	0.56 (0.32-0.98)	<.05	0.67 (0.36-1.27)	.212
	High (reference)	1.00		1.00		1.00		1.00	
Model 3	Low	0.41 (0.24-0.67)	<.01	0.48 (0.12-1.95)	.298	0.33 (0.19-0.57)	<.001	0.68 (0.28-1.67)	.354
	Moderate	0.44 (0.25-0.77)	<.01	0.46 (0.25-0.84)	<.05	0.44 (0.23-0.87)	<.05	0.52 (0.25-1.09)	.082
	High (reference)	1.00		1.00		1.00		1.00	
Women									
Model 1	Low	0.84 (0.59-1.20)	.318	0.76 (0.39-1.46)	.396	0.61 (0.34-1.11)	.103	0.77 (0.49-1.22)	.264
	Moderate	0.98 (0.76-1.27)	.884	0.66 (0.48-0.92)	<.05	0.89 (0.54-1.46)	.630	0.96 (0.72-1.28)	.794
	High (reference)	1.00		1.00		1.00		1.00	
Model 2	Low	0.83 (0.60-1.15)	.264	1.17 (0.58-2.36)	.645	0.99 (0.55-1.79)	.983	0.81 (0.50-1.32)	.389
	Moderate	0.91 (0.69-1.19)	.471	0.89 (0.68-1.16)	.374	1.04 (0.61-1.77)	.882	0.94 (0.66-1.35)	.744
	High (reference)	1.00		1.00		1.00		1.00	
Model 3	Low	0.92 (0.65-1.31)	.653	1.78 (0.57-5.54)	.309	1.20 (0.54-2.64)	.649	0.71 (0.40-1.25)	.227
	Moderate	0.96 (0.69-1.34)	.813	1.16 (0.70-1.92)	.564	1.13 (0.57-2.27)	.715	0.85 (0.54-1.36)	.497
	High (reference)	1.00		1.00		1.00		1.00	

NOTE. Model 1 includes as a predictor only for specific lifestyle-related risk factor; model 2 adds age, race, education and income levels, and menopausal for women as predictors; and model 3 includes model 2 and other modifiable factors.

*BMI represents body-mass index; in the ALL group the model was also adjusted for BMI as a continuous variable.

†ORs represent the metabolic syndrome odds ratios for modifiable lifestyle factors.

‡CI represents 95% confidence interval, ORs ± 1.96 SE.

intake in normal weight men, however, was accompanied by a significantly lower risk of having the metabolic syndrome in all 3 regression models compared with a high CHO intake. In overweight men, the metabolic syndrome OR was lower in both low (model 3, OR = 0.33; CI, 0.19 to 0.57; $P <$ .001) and moderate CHO intake groups (model 3, OR = 0.44; CI, 0.23 to 0.87; $P <$ .05). There was no significant relationship between CHO intake and the risk of having the metabolic syndrome in obese men.

A moderate dietary CHO intake in normal weight women was associated with a lower risk of having the metabolic syndrome only in model 1. CHO intake had no impact on the risk of having the metabolic syndrome in models 2 and 3 for all 3 BMI categories in women.

Fat intake did not have a significant impact on the risk of having the metabolic syndrome in models 2 and 3. However, in model 1, for the overall BMI group, compared with a low-fat intake, a high-fat intake was associated with a lower risk of having the metabolic syndrome for both men (OR = 0.44; CI, 0.21 to 0.91; $P <$ .05) and women (OR = 0.58; CI, 0.41 to 0.81; $P <$ .01).

Alcohol Consumption

Overall, in men, light-to-moderate alcohol consumption was accompanied by a lower risk of having the metabolic syndrome compared with never drinking in model 1. This lower risk was no longer significant after controlling for the covariates in models 2 and 3 (Table 3). Heavy drinking in overweight men had a negative impact on the risk of having the metabolic syndrome (OR = 1.37; CI, 1.04 to 1.79; $P <$ .05).

In women, light-to-moderate and heavy alcohol consumption was accompanied by a significantly lower metabolic syndrome risk in all 3 models tested. Also, in obese women, heavy drinking was accompanied by a lower OR (0.56; CI, 0.32 to 0.98; $P <$ .05). In overweight women, reported light-to-moderate drinking tended (model 3, OR = 0.64; CI, 0.38 to 1.07; $P =$ .088) to be associated with a lower OR of having the metabolic syndrome.

Smoking

Subjects who reported never smoking did not have a significantly lower risk of having the metabolic syndrome in the univariate regression analysis compared with those who currently smoked. In the adjusted models, never smoking was accompanied by lower metabolic syndrome ORs in both men and women compared with current smoking (Table 4). In normal weight and overweight women, never smoking was associated with a significantly lower risk of having the metabolic syndrome compared with current smoking (model 3, OR = 0.51; CI, 0.28 to 0.94; $P <$ .05 and OR = 0.47; CI, 0.25 to 0.88; $P <$ .05, for normal weight and overweight women, respectively).

When an additional variable, such as total daily caloric intake, was included in model 3, the significance of the modifiable lifestyle factors already in the model did not change, nor did the magnitude of the coefficients for the additional variable reach significance in any of the sex or BMI groups (β coefficients ranged between 0.00004 and -0.0001, P values ranged between .08 and .80).

Table 3. Metabolic Syndrome ORs for Alcohol Consumption

		All		<25		25-29.9		≥30	
BMI* (kg/m^2)	Alcohol Intake	OR† (CI)‡	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value
Men									
Model 1	Light-moderate	0.57 (0.45-0.74)	<.001	0.52 (0.29-0.96)	<.05	0.59 (0.42-0.83)	<.01	0.70 (0.43-1.12)	.131
	Heavy	1.07 (0.80-1.43)	.637	1.15 (0.55-2.40)	.694	1.37 (1.05-1.78)	<.05	1.46 (0.76-2.80)	.243
	Never (reference)	1.00		1.00		1.00		1.00	
Model 2	Light-moderate	0.82 (0.61-1.09)	.169	0.84 (0.43-1.66)	.605	0.75 (0.56-1.00)	<.05	0.78 (0.47-1.27)	.303
	Heavy	1.22 (0.89-1.68)	.210	1.05 (0.50-2.19)	.898	1.43 (1.11-1.84)	<.01	1.43 (0.77-2.68)	.249
	Never (reference)	1.00		1.00		1.00		1.00	
Model 3	Light-moderate	0.89 (0.64-1.23)	.457	0.79 (0.39-1.60)	.498	0.82 (0.61-1.10)	.178	0.79 (0.45-1.40)	.409
	Heavy	1.27 (0.89-1.81)	.180	1.03 (0.50-2.15)	.931	1.37 (1.04-1.79)	<.05	1.56 (0.84-2.92)	.154
	Never (reference)	1.00		1.00		1.00		1.00	
Women									
Model 1	Light-moderate	0.44 (0.37-0.53)	<.001	0.40 (0.24-0.55)	<.001	0.46 (0.34-0.62)	<.001	0.65 (0.46-0.91)	<.05
	Heavy	0.60 (0.46-0.79)	<.01	0.71 (0.33-1.49)	.351	0.69 (0.42-1.15)	.148	0.63 (0.38-1.05)	.076
	Never (reference)	1.00		1.00		1.00		1.00	
Model 2	Light-moderate	0.78 (0.64-0.95)	<.05	0.75 (0.50-1.12)	.158	0.75 (0.53-1.08)	.118	0.85 (0.62-1.16)	.295
	Heavy	0.70 (0.50-0.97)	<.05	0.90 (0.43-1.88)	.780	0.83 (0.55-1.27)	.381	0.59 (0.34-1.01)	.054
	Never (reference)	1.00		1.00		1.00		1.00	
Model 3	Light-moderate	0.76 (0.61-0.95)	<.05	0.70 (0.44-1.14)	.148	0.72 (0.49-1.05)	.089	0.86 (0.63-1.18)	.346
	Heavy	0.62 (0.44-0.87)	<.01	0.70 (0.31-1.58)	.374	0.64 (0.38-1.07)	.088	0.56 (0.32-0.98)	<.05
	Never (reference)	1.00		1.00		1.00		1.00	

NOTE. Model 1 includes as a predictor only for specific lifestyle-related risk factor; model 2 adds age, race, education and income levels, and menopausal for women as predictors; and model 3 includes model 2 and other modifiable factors.

*BMI represents body-mass index; in the ALL group the model was also adjusted for BMI as a continuous variable.

†ORs represent the metabolic syndrome odds ratios for modifiable lifestyle factors.

‡CI represents 95% confidence interval, ORs ± 1.96 SE.

Table 4. Metabolic Syndrome ORs for Smoking Habit

		All		<25		25-29.9		≥30	
BMI* (kg/m^2)	Smoking Status	OR† (CI)‡	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value	OR (CI)	*P* Value
Men									
Model 1	Never	0.96 (0.76-1.21)	.694	0.69 (0.32-1.49)	.333	0.66 (0.39-1.12)	.120	0.86 (0.49-1.53)	.598
	Previous	1.92 (1.49-2.47)	<.001	1.10 (0.54-2.24)	.798	1.50 (0.87-2.58)	.136	1.06 (0.64-1.76)	.814
	Current (reference)	1.00		1.00		1.00		1.00	
Model 2	Never	0.62 (0.45-0.86)	<.01	0.65 (0.30-1.42)	.267	0.61 (0.37-1.00)	.051	0.86 (0.44-1.68)	.645
	Previous	0.76 (0.55-1.05)	.095	0.54 (0.27-1.10)	.088	0.87 (0.52-1.46)	.586	0.78 (0.43-1.41)	.394
	Current (reference)	1.00		1.00		1.00		1.00	
Model 3	Never	0.63 (0.45-0.90)	<.05	0.57 (0.26-1.24)	.149	0.62 (0.37-1.05)	.076	0.89 (0.45-1.74)	.717
	Previous	0.78 (0.57-1.08)	.128	0.52 (0.26-1.04)	.065	0.93 (0.58-1.49)	.744	0.76 (0.39-1.46)	.395
	Current (reference)	1.00		1.00		1.00		1.00	
Women									
Model 1	Never	1.08 (0.83-1.40)	.571	0.84 (0.43-1.63)	.593	0.87 (0.52-1.45)	.593	1.13 (0.67-1.93)	.630
	Previous	1.51 (1.15-2.00)	<.01	1.35 (0.81-2.24)	.240	1.18 (0.63-2.22)	.596	1.78 (1.05-3.01)	<.05
	Current (reference)	1.00		1.00		1.00		1.00	
Model 2	Never	0.63 (0.45-0.88)	<.01	0.55 (0.29-1.01)	.055	0.51 (0.27-0.95)	<.05	0.94 (0.56-1.57)	.799
	Previous	0.77 (0.54-1.10)	.141	0.81 (0.45-1.46)	.465	0.66 (0.31-1.41)	.277	1.24 (0.75-2.05)	.391
	Current (reference)	1.00		1.00		1.00		1.00	
Model 3	Never	0.58 (0.41-0.81)	<.01	0.51 (0.28-0.94)	<.05	0.47 (0.25-0.88)	<.05	0.90 (0.54-1.51)	.685
	Previous	0.76 (0.53-1.07)	.116	0.78 (0.42-1.46)	.422	0.66 (0.32-1.36)	.250	1.27 (0.75-2.14)	.362
	Current (reference)	1.00		1.00		1.00		1.00	

NOTE. Model 1 includes as a predictor only for specific lifestyle-related risk factor; model 2 adds age, race, education and income levels, and menopausal for women as predictors; and model 3 includes model 2 and other modifiable factors.

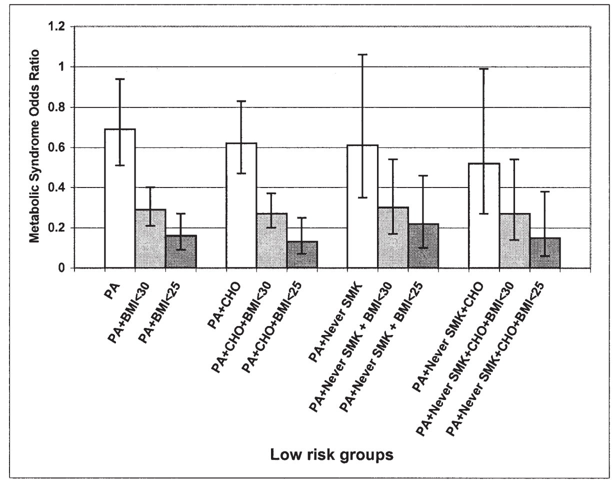
*BMI represents body-mass index; in the ALL group the model was also adjusted for BMI as a continuous variable.

†ORs represent the metabolic syndrome odds ratios for modifiable lifestyle factors.

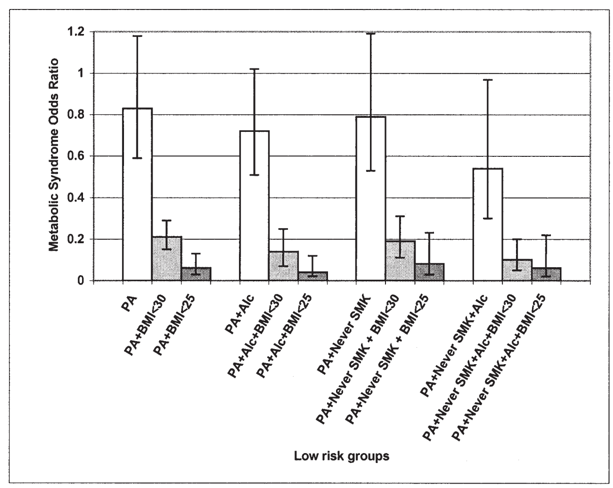
‡CI represents 95% confidence interval, ORs ± 1.96 SE.

Sex Differences

There were no significant interaction effects with physical activity or smoking habits in relation to the metabolic syndrome between genders in the overall BMI group. However, the interaction between alcohol intake and gender was significant with heavy drinking (OR = 1.90; CI, 1.13 to 3.19; $P < .05$) indicating a greater OR for the metabolic syndrome in heavy drinking men compared with women. There was also a trend for an interaction between CHO intake and gender with an OR of 0.70 (CI, 0.45 to 1.07; $P = .096$) at a moderate CHO intake level.



Men



Women

Fig 1. ORs of having the metabolic syndrome with low-risk behaviors or lifestyle. Factors: physically active, low and moderate CHO intake (for men), light-to-moderate alcohol consumption (for women), and nonsmoking, overall (white bar) and with additional conditions of normal weight (BMI < 25 kg/m^2, black bar) and overweight (BMI < 30 kg/m^2, gray bar). In each case, the reference group for the comparison is with subjects who do not qualify for that low-risk behavior or lifestyle category. PA, physically active; CHO, low and moderate carbohydrate intakes; Alc, light-to-moderate alcohol consumption; SMK, smoking.

Combinations of Lifestyle Behaviors

The odds of having the metabolic syndrome when a combination of low-risk lifestyle factors and BMI are present are shown in Fig 1 for men (Fig 1A) and women (Fig 1B). The low-risk factors identified included being physically active, having a low or moderate CHO intake for men or a light-to-moderate alcohol consumption for women, and never smoking. Four sets of combined factors are presented within each gender category and the respective sets include ORs for the 3 condition models.

Being physically active, compared with being physically inactive, regardless of BMI, was associated with a lower OR of having the metabolic syndrome by 31% in men (OR = 0.69; CI, 0.51 to 0.94; $P < .05$) and 17% in women (OR = 0.83; CI, 0.59 to 1.18; $P = .293$). Furthermore, being physically active combined with a BMI below 30 kg/m^2 or below 25 kg/m^2 was associated with a substantially lower risk of having the metabolic syndrome: 71% (OR = 0.29; CI, 0.21 to 0.40; $P < .001$) and 84% (OR = 0.16; CI, 0.09 to 0.27; $P < .001$) in normal weight and overweight men and 79% (OR = 0.21; CI, 0.15 to 0.29; $P < .001$) and 94% (OR = 0.06; CI, 0.03 to 0.13; $P < .001$) in normal weight and overweight women (Fig 1).

If, in addition to being physically active, men consumed a low or moderate CHO diet and women had a light-to-moderate alcohol intake, the metabolic syndrome OR was reduced to 0.62 (CI, 0.47 to 0.83; $P < .01$) and 0.72 (CI, 0.51 to 1.02; $P = .062$), respectively. If individuals had BMIs <30 or 25 kg/m^2, the respective ORs for having the metabolic syndrome were even lower in both men (0.27, CI, 0.20 to 0.37; $P < .001$; 0.13, CI, 0.07 to 0.25; $P < .001$, for BMI < 30 and 25 kg/m^2, respectively) and women (0.14, CI, 0.07 to 0.25; $P < .001$; 0.04, CI, 0.02 to 0.12; P < 0.001, for BMI < 30 and 25 kg/m^2, respectively).

When being physically active and never smoking were combined, metabolic syndrome ORs were 0.61 (CI, 0.35 to 1.06; $P = .076$) for men and 0.79 (CI, 0.53 to 1.19; $P = .255$) for women, in general. With BMIs < 30 or 25 kg/m^2, the respective ORs for having the metabolic syndrome were again even lower in men (0.30, CI, 0.17 to 0.54; $P < .001$; 0.22, CI, 0.10 to 0.46; $P < .001$) and women (0.19, CI, 0.11 to 0.31; $P < .001$; 0.08, CI, 0.03 to 0.23; $P < .001$).

When individuals had all of the following low-risk lifestyle behaviors, being physically active, having a low or moderate CHO intake for men or light-to-moderate alcohol consumption for women, and being a nonsmoker, the metabolic syndrome ORs were further reduced in both men (OR = 0.52; CI, 0.27 to 0.99; $P < .05$) and women (OR = 0.54; CI, 0.30 to 0.97; $P < .05$). Subjects who exhibited all of these low-risk behaviors combined and who had a BMI < 30 or 25 kg/m^2 had a substantially lower risk of being diagnosed with the metabolic syndrome, 73% and 85% lower in men and 90% and 94% lower in women, respectively.

DISCUSSION

The metabolic syndrome, a prevalent within-individual clustering of CVD risk factors, is affected by lifestyle behaviors including physical activity, diet, smoking, and drinking habits.[1,12] In the present study, we developed logistic regression models examining the independent impact of these lifestyle factors on the odds of having the metabolic syndrome within different BMI categories. Our models reveal that the likelihood of being diagnosed with the metabolic syndrome is lower in individuals who exhibit specific lifestyle behaviors either alone or in combination, particularly if their BMI is maintained in the non-obese range.

Lifestyle Factors and Risk Modification

Physical activity level. Of the examined lifestyle factors, the most strongly associated with a lower risk of having the metabolic syndrome was physical activity. Our findings are in agreement with recent epidemiologic studies that link greater physical activity with a reduced risk of having the metabolic syndrome[17-22] and coronary heart disease.[23]

However, in contrast to others,[24] the observed significant lower OR between physical activity level and metabolic syndrome in univariate analysis persisted after controlling for age, ethnicity, BMI, socioeconomic status, as well as when additionally controlling for smoking, drinking, and dietary habits. It is known that a lower level of physical activity is associated with low socioeconomic status and a higher mortality from CVD.[8] In addition, low education level may increase CVD risk through unhealthy dietary habits,[25-27] higher rates of smoking, and overweight.[28]

Physical activity could exert its protective effects on the metabolic syndrome through improvements in plasma lipid concentrations, particularly through increases in HDL cholesterol concentrations,[29-33] decreases in triglyceride concentrations,[34] or both.[22,35,36] In addition, physical activity has been shown to lower blood pressure,[22,37] improve glucose tolerance[38,39] and insulin sensitivity,[40,41] and reduce the risk of being diagnosed with type 2 diabetes.[9,42]

CHO intake. In addition to physical activity level, our models reveal a relatively low risk of having the metabolic syndrome in men who consume a low or moderate CHO diet. High-CHO intake has been shown to be associated with lower HDL cholesterol and higher triglyceride concentrations, 2 criteria for the diagnosis of the metabolic syndrome.[43,44] Parks and Hellerstein[44] reported that the effects of high CHO consumption on triglyceride concentrations appear to be greater in men than women, which may, in part, explain the different gender effects of CHO intake on metabolic syndrome risk. However, our analyses did not discriminate between simple and complex CHO and therefore it is not known whether the association between CHO and the odds of having the metabolic syndrome is due to high intakes of simple sugars consumed in the American population and may not be indicative of high complex CHO consumption.

Alcohol intake. A "J-shaped" relation exists between alcohol intake and CVD risk with minimal risk of CVD at light-to-moderate alcohol intakes.[45-47] Light-to-moderate alcohol consumption may lower CVD risk by increasing HDL cholesterol concentrations, inhibiting low-density lipoprotein cholesterol oxidation, decreasing blood pressure and insulin levels, and increasing insulin sensitivity, thus improving factors that have been associated with the metabolic syndrome.[45-47] In accord with earlier studies, we also observed a lower risk of having the metabolic syndrome in light-to-moderate drinkers. With heavy drinking, men had an increased risk of having metabolic syndrome, consistent with a J-shaped effect of alcohol on CVD risk. However, compared with nondrinkers, an even lower metabolic syndrome OR was observed in heavy drinking women than in their light-to-moderate drinking counterparts. The reason for this gender difference is uncertain and requires replication and further investigation.

Combined measures. Our logistic models suggest that the majority of Americans would not be diagnosed with the metabolic syndrome if they had appropriate lifestyle behaviors, such as being physically active, having a low CHO intake for men or light-to-moderate drinking habits for women, and not smoking, and had a BMI < 30 kg/m^2. These results are in agreement with earlier studies that found that, in women, combining several lifestyle behaviors, including maintaining a BMI < 25 kg/m^2, was associated with a 90% lower risk of having type 2 diabetes compared with women without these behaviors.[9] Walkins et al[48] reported that exercise combined with weight loss was a more effective treatment compared with exercise alone for hyperinsulinemia and lowering of diastolic blood pressure in patients with the metabolic syndrome.

Our models show that having a combination of several "low-risk" behaviors in nonsmokers, such as being physically active, consuming a diet low or moderate in CHO (for men) and light-to-moderate in alcohol (for women), substantially lowers the risk of having the metabolic syndrome by approximately 45%. If BMI was in the normal weight or non-obese range, this reduction in the risk of having the metabolic syndrome would increase to approximately 85% or 73%, respectively, for men and 94% or 90%, respectively for women.

Study Limitations

The purpose of developing these logistic models was to estimate the potential effects of lifestyle changes on the risk of developing the metabolic syndrome. Ideally, such models are developed from an experimental or cohort longitudinal database and not from cross-sectional data. As a result, causal pathways underlying the observed associations between the lifestyle factors examined here and the metabolic syndrome cannot be inferred. Longitudinal studies are needed to confirm the effects of lifestyle modifications on the metabolic syndrome. Nevertheless, using NHANES data enabled us to assess the strength of the relationships between these factors and the metabolic syndrome in a representative sample of the US population and to gauge the potential for population benefits. Regression models further adjusting for various potential confounding factors allowed us to assess the effects of the covariates, such as age, ethnicity, education and income levels, and menopausal status, on the relationships between lifestyle factors and metabolic syndrome (results not presented). When an additional covariate was added into the final model, the coefficients for the covariate were small and did not reach statistical significance indicating a good fit of the final model to the data.

Conclusions

Although the cross-sectional nature of the present study does not allow causality to be inferred, the associations between "healthy" behaviors and the metabolic syndrome observed suggest that combining certain lifestyle behaviors places an individual at lower risk of having the metabolic syndrome. Whether the adoption of such behaviors by individuals will result in a lowering of the prevalence of the metabolic syndrome remains unknown. Nevertheless, our results lead us to posit that this may be the case and thus have important value for public health recommendations.

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