Food and nutrient intakes and their associations with lower BMI in middle-aged US adults: the International Study of Macro-/Micronutrients and Blood Pressure (INTERMAP)[1–3]

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ABSTRACT

Background: Clinical trial data show that reduction in total energy intake enhances weight loss regardless of the macronutrient composition of the diet. Few studies have documented dietary patterns or nutrient intakes that favor leanness [BMI (in kg/m^2) ≤25] in free-living populations.

Objective: This investigation examined associations of usual energy, food, and nutrient intakes with BMI among US participants of the International Study of Macro-/Micronutrients and Blood Pressure (INTERMAP).

Design: The INTERMAP is an international cross-sectional study of dietary factors and blood pressure in men and women (ages 40–59 y) that includes 8 US population samples. The present study included data from 1794 Americans who were not consuming a special diet and who provided four 24-h dietary recalls and 2 timed 24-h urine collections. Multivariable linear regression with the residual method was used to adjust for energy intake; sex-specific associations were assessed for dietary intakes and urinary excretions with BMI adjusted for potential confounders including physical activity.

Results: Lower energy intake was associated with lower BMI in both sexes. Univariately, higher intakes of fresh fruit, pasta, and rice and lower intakes of meat were associated with lower BMI; these associations were attenuated in multivariable analyses. Lower urinary sodium and intakes of total and animal protein, dietary cholesterol, saturated fats, and heme iron and higher urinary potassium and intakes of carbohydrates, dietary fiber, and magnesium were associated with lower BMI in both sexes.

Conclusion: The consumption of foods higher in nutrient-dense carbohydrate and lower in animal protein and saturated fat is associated with lower total energy intakes, more favorable micronutrient intakes, and lower BMI. *Am J Clin Nutr* 2012;96:483–91.

INTRODUCTION

Intense debate has occurred over optimal diet composition for achieving and maintaining favorable body weight (1–4). Recent evidence from a large randomized clinical trial in the United States showed that variation of dietary protein, carbohydrate, or fat composition has no particular advantage in achieving and maintaining weight loss unless alterations in total energy intake, energy expenditure, or both occur (5). These findings confirm that weight loss occurs as a function of energy deficit regardless of the dietary sources. Although the current obesity epidemic dominates research attention, there remains a subgroup of individuals who maintain normal weight [BMI (in kg/m^2) <25] despite the obesogenic environment. Determining the dietary behaviors of such individuals could help shed light on how to succeed in the practice of weight control and help others to prevent overweight and obesity. Stated generally, the question is as follows: Among free-living populations, does nutrient and food composition of the diet vary by BMI—ie, facilitating or impeding the ability of people to avoid overweight or obesity? Paradoxically, BMI is inversely associated with micronutrient (eg, vitamin and mineral) intake (6–9), which leaves many overweight and obese individuals nutritionally deficient (10–12). Thus, simultaneous explorations are needed of food, nutrient, and energy intakes to clarify associations between dietary composition (macro-/micronutrient) and BMI. Data on these associations in general populations are sparse.

This study measured both ecologic and individual-level associations of energy, food, and nutrient intakes with BMI in middle-aged adults from the US population samples of the International Study of Macro-/Micronutrients and Blood Pressure (INTERMAP). It assessed whether lean men and women from the general population reported lower energy intake and other food pattern differences when compared with overweight/obese in-

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dividuals. Such findings could identify eating patterns that accompany successful weight control in free-living individuals.

SUBJECTS AND METHODS

Population samples and field methods

Background, aims, design, methods, and descriptive statistics of the INTERMAP have been reported in detail (13). Briefly, in 1996–1999, INTERMAP surveyed 4680 men and women aged 40–59 y from Japan (4 samples), the People's Republic of China (3 samples), the United Kingdom (2 samples), and the United States (8 samples; n = 2195). Each sample was selected randomly from a population list and stratified by age and sex to give approximately equal numbers in each of four 10-y age-sex groups. Each participant attended 4 study visits at the local INTERMAP research center: 2 visits on consecutive days, with an additional 2 visits on consecutive days 3–6 wk later. Wherever possible, one visit for each participant included a weekend day (or an equivalent rest day) according to his or her work schedule. During study visits, trained staff recorded 8 standardized blood pressure measurements (2/visit). Participants' height and weight without shoes were measured at the first and third visits (14); BMI was calculated as the ratio of weight to standing height squared (kg/m^2). Questionnaire data were obtained by interview on demographic and other possible confounding factors, including education, occupation, physical activity, smoking, medical history, current use of a special diet, and medication use. Physical activity was assessed by an INTERMAP questionnaire: participants were asked to report the number of hours per day spent performing heavy, moderate, and light physical activity (13). Informed consent was obtained from all participants, and the study design and data collection and analyses were performed in accordance with the Helsinki Declaration of 1975 as revised in 1983 and the ethical standards of the supervising institutional review boards of all centers involved.

Collection of dietary information

Trained interviewers collected dietary data (including dietary supplement use) at each of the 4 visits via the in-depth multipass 24-h recall method (15). All foods and beverages consumed in the previous 24 h were recorded. To aid accurate recall, fresh foods of varied standardized portion sizes, food and drink models, containers of various types and sizes, and photographs were used. Interviewers used neutral probing techniques to check for the completeness of items reported and for details such as brand names of foods, quantities, processing methods, additions during cooking and/or at the table, and amounts left on the plate (13). In the United States, dietary information was directly computerized with the use of a program to guide on-screen coding. Nutrient intakes of participants were calculated from US-specific food tables. Daily alcohol consumption (amount and type of alcoholic beverage) over the previous 7 d and, for abstainers, information

TABLE 1
Characteristics of men and women (aged 40–59 y) by category of BMI, with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	BMI (kg/m^2)					
	Men			Women		
Characteristics	<25.0 (n = 202)	25.0–29.9 (n = 414)	≥30.0 (n = 331)	<25.0 (n = 316)	25.0–29.9 (n = 256)	≥30.0 (n = 275)
BMI (kg/m^2)	23.1 ± 1.6[2]	27.6 ± 1.5	34.1 ± 3.9	22.6 ± 1.7[3]	27.3 ± 1.4[3]	35.9 ± 5.0[3]
Age (y)	48.7 ± 5.4	49.1 ± 5.5	48.9 ± 5.2	48.5 ± 5.3	49.5 ± 5.4	48.9 ± 5.5
Race-ethnicity [n (%)][4]						
Non-Hispanic white	108 (19.9)	250 (46.0)	185 (34.1)	198 (45.2)	127 (29.0)	113 (25.8)
African American	25 (19.3)	56 (43.1)	49 (37.7)	28 (18.2)	48 (31.2)	78 (50.7)
Hispanic	16 (13.7)	43 (36.8)	58 (49.6)	18 (15.3)	38 (32.2)	62 (52.5)
Asian	50 (34.5)	61 (42.1)	34 (23.5)	67 (53.2)	41 (32.5)	18 (14.3)
Other	3 (25.0)	4 (33.3)	5 (41.7)	5 (45.5)	2 (18.2)	4 (36.4)
Education (y)[5]	15.8 ± 3.3	15.8 ± 3.2	14.8 ± 2.8	15.3 ± 2.7	14.7 ± 3.0[3]	13.7 ± 2.6[3]
Systolic blood pressure (mm Hg)[5]	113.0 ± 11.3	120.6 ± 12.3	123.9 ± 11.7	110.7 ± 13.1[3]	116.8 ± 13.8[3]	122.5 ± 14.1
Diastolic blood pressure (mm Hg)[5]	70.7 ± 8.5	76.1 ± 9.0	78.3 ± 9.6	68.2 ± 8.4[3]	72.1 ± 9.2[3]	73.6 ± 9.0[3]
History of CVD or diabetes [n (%)][4]	17 (8.4)	40 (9.7)	60 (18.1)	28 (8.9)	27 (10.6)	47 (17.1)
Current smoker [n (%)][6]	53 (26.2)	86 (20.8)	51 (15.4)	39 (12.3)[3]	46 (18.0)[3]	41 (14.9)
Dietary supplement use [n (%)][4]	110 (54.5)	187 (45.2)	148 (44.7)	205 (64.9)[3]	130 (50.8)[3]	131 (47.6)
Moderate/heavy physical activity (h/d)[7]	2.6 ± 1.1	2.6 ± 1.0	2.2 ± 1.1	1.9 ± 1.1[3]	2.0 ± 1.1[3]	2.3 ± 1.2

[1] Participants who reported special diets were excluded (n = 401). Tests for trend or differences in distribution across BMI categories were made by using chi-square analysis or generalized linear models as appropriate; percentages may not equal 100% because of rounding. CVD, cardiovascular disease; INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure.

[2] Mean ± SD (all such values).

[3] Significantly different from men within BMI category, $P < 0.05$.

[4] Significantly different distribution across BMI categories for men and women, $P < 0.05$.

[5] P-trend < 0.05 across BMI categories for men and women.

[6] Significantly different distribution across BMI categories for men, $P < 0.05$.

[7] P-trend < 0.05 across BMI categories for women.

on previous drinking were obtained by interview twice, at the first and third visits. These data were collected in addition to those on alcohol intake from the four 24-h dietary recalls.

Assessment of urinary measures

Two timed 24-h urine specimens were collected for measurement of urinary albumin, sodium, potassium, creatinine, urea, amino acids, and multiple metabolites (13). Timed collections were started at the research center on the first and third visits and completed at the center the following day. Urine aliquots were stored frozen at −20°C before being shipped frozen to a central laboratory in Leuven, Belgium, where analyses were performed with extensive internal and external quality control; subsequent analyses were performed at a central laboratory in London, United Kingdom. Individual excretion values were calculated as the product of concentrations in the urine and urinary volumes corrected to 24 h.

Exclusions

Of the 4680 total INTERMAP participants, the current analyses are based on the 2195 US participants. Participants who reported the use of a special diet for medical or weight-loss purposes were excluded (n = 401), which left a total of 1794 US adults (947 men, 847 women; ie, 81.7% of the US INTERMAP sample).

Statistical methods

Food data for individuals were converted into food subgroups (17 food subgroups) and nutrients (83 nutrients) with the use of country-specific tables on the nutrient composition of foods, updated and standardized across countries by the Nutrition Coordinating Center, University of Minnesota (13, 14). Intakes of macronutrients (nutrients supplying energy) were calculated as absolute intake and as the percentage of total energy. Protein from animal and vegetable sources and its constituent amino acids were additionally expressed as a percentage of total protein. Intakes of micronutrients were calculated as absolute intake and as intake/1000 kcal. For foods/food subgroups, intakes were calculated as absolute intakes (g) and as g/1000 kcal. Measurements per person were averaged for blood pressure, food, and nutrient variables across the 4 visits.

For descriptive statistics, means and SDs (or frequencies and percentages) were calculated across BMI categories (normal weight: <25.0; overweight: 25.0–29.9; obese: ≥30.0) and compared by using chi-square analysis, generalized linear models, or

TABLE 2

Unadjusted food intakes (g/1000 kcal) of men and women (aged 40–59 y) by category of BMI, with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	BMI (kg/m^2)					
	Men			Women		
Food groups/subgroups[2]	<25.0 (n = 202)	25.0–29.9 (n = 414)	≥30.0 (n = 331)	<25.0 (n = 316)	25.0–29.9 (n = 256)	≥30.0 (n = 275)
Total fruit	114.8 (48.7–193.9)	88.1 (39.8–175.0)	88.2 (34.2–166.7)	123.4 (64.5–197.6)	111.0 (58.1–208.0)	101.9 (44.4–186.5)
Fresh fruit[3]	45.1 (13.7–84.5)	29.0 (5.9–66.2)	26.2 (4.6–65.6)	54.1 (21.8–94.6)	40.7 (8.6–90.9)	31.5 (6.2–72.2)
Total vegetables[4]	112.1 (79.4–171.9)	121.2 (83.7–153.1)	110.7 (79.8–154.9)	122.8 (90.6–183.9)	128.0 (94.2–177.3)	115.0 (81.1–154.0)
Whole grains[4]	16.6 (4.8–30.5)	13.1 (4.6–24.1)	11.7 (4.2–22.4)	16.6 (7.6–32.0)	14.7 (6.1–29.0)	13.5 (5.3–25.3)
Pasta and rice[3]	36.4 (14.7–89.9)	30.9 (10.9–61.4)	21.5 (5.3–47.3)	37.3 (13.6–70.8)	29.5 (7.5–56.7)	23.3 (8.4–48.9)
Nuts and nut butters[4]	0.8 (0.0–4.5)	0.9 (0.0–4.7)	0.5 (0.0–3.5)	1.3 (0.0–4.8)	1.0 (0.0–4.5)	0.5 (0.0–3.1)
Dried peas and legumes[4]	0.0 (0.0–10.7)	0.0 (0.0–13.6)	0.0 (0.0–15.6)	0.0 (0.0–9.2)	0.0 (0.0–10.0)	0.0 (0.0–13.0)
Low-fat dairy[4]	0.3 (0.0–40.8)	0.0 (0.0–39.6)	0.0 (0.0–29.5)	4.3 (0.0–87.1)	3.3 (0.0–59.9)	3.0 (0.0–41.9)
Fish, fish roe, and shellfish[4]	3.4 (0.0–15.6)	1.9 (0.0–13.7)	0.0 (0.0–11.4)	5.2 (0.0–14.3)	3.3 (0.0–14.0)	0.0 (0.0–12.0)
Poultry[4]	15.6 (5.5–25.2)	16.8 (6.6–30.7)	15.2 (5.5–29.2)	14.9 (6.4–27.0)	18.0 (6.7–31.4)	19.2 (9.3–32.1)
Beef, pork, veal, and game meats[3]	25.8 (11.4–41.2)	29.2 (17.6–43.1)	32.7 (21.8–48.8)	19.8 (7.5–34.3)	23.7 (11.8–41.6)	26.2 (13.7–42.3)
Processed meats[3]	4.5 (0.0–13.3)	5.3 (0.0–13.2)	8.7 (2.5–15.1)	2.7 (0.0–8.8)	4.5 (0.0–11.4)	6.2 (0.6–14.1)
Total visible fats[5]	16.1 (11.4–20.9)	17.3 (13.3–23.0)	17.2 (12.7–21.6)	18.0 (13.6–24.3)	18.5 (14.3–24.0)	17.9 (13.9–22.8)
Snacks and sweets	21.0 (10.4–31.6)	21.1 (11.8–32.2)	19.0 (10.0–31.5)	26.6 (16.9–38.2)	24.9 (14.8–36.9)	23.3 (15.1–34.3)
Alcoholic beverages[3]	6.0 (0.0–112.2)	0.3 (0.0–109.4)	0.0 (0.0–79.7)	0.0 (0.0–16.1)	0.0 (0.0–5.1)	0.0 (0.0–0.0)
Carbonated soft drinks[5]	483.6 (275.7–655.0)	477.8 (295.4–707.1)	525.0 (355.7–762.2)	566.1 (371.7–832.1)	581.4 (382.2–898.1)	634.7 (395.7–946.9)
Sugar-sweetened beverages[4]	105.0 (32.0–204.8)	98.8 (29.0–216.2)	119.6 (24.8–242.6)	51.3 (0.0–143.0)	81.8 (0.0–218.0)	142.0 (41.9–260.0)

[1] All values are medians; IQRs in parentheses. Tests for trend across BMI categories were made by using generalized linear models. INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure.

[2] All food groups were ranked before statistical testing to approximate normality. Total fruit includes fresh fruit, fruit juices, and sweetened fruits; pasta and rice include recipes; total visible fats include animal fats, margarines, table spreads, oils, shortenings, and dressings; carbonated soft drinks include sodas and colas including diet beverages; sugar-sweetened beverages include uncarbonated and carbonated soft drinks, fruit drinks (excluding 100% fruit juices), and lemonade but not diet beverages.

[3] P-trend < 0.05 across BMI categories for men and women.

[4] P-trend < 0.05 across BMI categories for women.

[5] P-trend < 0.05 across BMI categories for men.

Kruskal-Wallis tests, as appropriate. Because a large proportion of participants reported no moderate/heavy physical activity and were therefore assigned a value of zero, a value of 1 was added to all measures of physical activity and was natural log transformed to approximate normality before statistical testing. For food/food subgroup intakes across BMI categories, median and interquartile ranges were used, and median values were compared across BMI categories by using the Kruskal-Wallis test.

For multivariable analyses of the continuous associations of nutrient/food intakes and urinary measures with BMI, linear regression with the residual method was used to examine these associations independent of total energy intake. Specifically, linear regression was used to "predict" individual food and nutrient intakes and urinary measures on the basis of total energy intake (kcal/d), and the residual value for each regression was calculated by subtracting the observed value from the predicted value. The continuous associations of the residual values of nutrient/food intakes and urinary measures with BMI were examined by using linear regression with adjustment for age, sex, smoking status (current compared with never/former), dietary supplement use (yes or no), history of cardiovascular disease or diabetes (yes or no), moderate/heavy physical activity (h/d), and total energy intake (kcal/d). Regression models were fit separately in men and women, and between-sex heterogeneity of regression coefficients was tested by interaction terms by using full models. All nutrient data presented exclude supplement intake. Sensitivity analyses were performed with nutrient data that included dietary supplement use to examine its influence on the observed associations with BMI. Analyses were performed with SAS version 9.2 (SAS Institute).

RESULTS

Descriptive statistics

The characteristics of US INTERMAP participants by sex and BMI category are summarized in **Table 1**. Mean age was similar across BMI strata in both men and women. Among non-Hispanic white and Asian participants, higher proportions of men were overweight or obese compared with women. Less than 20% of African Americans and Hispanics (men or women) were of normal weight. Higher educational attainment and dietary supplement use, lower blood pressure, and lower prevalence of cardiovascular disease or diabetes history were observed in normal-weight men and women in comparison with those who were overweight or obese. The highest prevalence of current smoking was observed in normal-weight individuals among men and in overweight participants among women. Reported physical activity was similar across BMI categories among men and lower in normal-weight women compared with those who were overweight or obese. Because the normal-weight BMI category was defined as <25.0, it is important to note that only 5 individuals were underweight (BMI <18.5), and the exclusion of these participants from categorical analyses did not significantly influence the reported associations.

Food and food subgroup intakes and BMI

Ecologic analyses

Unadjusted median values and IQRs for intakes of foods/food subgroups are presented according to sex and BMI category in **Table 2**. Normal-weight men and women exhibited the highest intakes of total and fresh fruit, whole grains, pasta and rice, fish, and alcoholic beverages and the lowest intakes of beef, pork, veal, and game meats and processed meats compared with those who were overweight or obese; however, tests for trend across BMI categories were not significant for total and fresh fruit, whole grains, or fish among men. Among women, those who were of normal weight reported the highest intakes of low-fat dairy, nuts and nut butters, and snacks and sweets along with the lowest intakes of poultry, dried peas and legumes, and sugar-sweetened beverages; these associations were not observed in men. Obese women reported consuming the highest amount of carbonated and sugar-sweetened beverages of all sex and BMI categories.

TABLE 3

Standardized regression coefficients for association between food intake (g/d) and category of BMI (kg/m^2) in men and women (aged 40–59 y), with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	Men (n = 947)			Women (n = 847)		
Food/food subgroup[2]	ST β	SE	P value	ST β	SE	P value
Total fruit	−0.11	0.16	0.46	−0.23	0.20	0.24
Fresh fruit	−0.35	0.15	0.02	−0.34	0.20	0.10
Total vegetables	−0.11	0.15	0.47	−0.10	0.20	0.61
Total grains	−0.10	0.15	0.53	−0.23	0.20	0.25
Whole grains	−0.27	0.15	0.07	−0.58	0.20	<0.01
Pasta and rice[3]	−0.64	0.20	<0.01	−0.38	0.24	0.12
Nuts and nut butters	−0.31	0.15	0.04	−0.28	0.20	0.16
Dried peas and legumes[3]	−0.08	0.16	0.62	0.19	0.21	0.37
Low-fat dairy[3]	−0.21	0.15	0.18	−0.25	0.21	0.24
Fish, fish roe, and shellfish	0.35	0.16	0.03	−0.40	0.20	0.05
Poultry[3]	0.19	0.15	0.21	0.41	0.20	0.04
Beef, pork, veal, and game meats	0.66	0.15	<0.001	0.46	0.20	0.02
Processed meats[3]	0.28	0.15	0.07	0.90	0.20	<0.001
Total visible fats	0.10	0.15	0.51	−0.30	0.20	0.13
Snacks and sweets	−0.32	0.15	0.04	−0.39	0.20	0.05
Alcoholic beverages	−0.33	0.15	0.03	−0.23	0.20	0.26
Carbonated soft drinks	0.65	0.15	<0.001	0.94	0.19	<0.001
Sugar-sweetened beverages[3]	−0.09	0.15	0.58	0.41	0.22	0.06

[1] Associations of food intakes with BMI were assessed with linear regression by using the residual method to examine associations independent of total energy intake. Regression coefficients are presented for residual values from total energy intake and were standardized per 1-SD sex-specific difference in residual values. All models were adjusted for age, education (y), race-ethnicity, smoking status (yes or no), history of high blood pressure or cardiovascular disease (yes or no), dietary supplement use (yes or no), moderate or heavy physical activity (h/d), and total energy intake (kcal). INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure; ST, standardized.

[2] Total fruit includes fresh fruit, fruit juices, and sweetened fruits; pasta and rice include recipes; total visible fats include animal fats, margarines, table spreads, oils, shortenings, and dressings; carbonated soft drinks include sodas and colas including diet beverages; sugar-sweetened beverages include uncarbonated and carbonated soft drinks (eg, soda), fruit drinks (excluding 100% fruit juices), and lemonade but exclude diet beverages.

[3] Test for between-sex heterogeneity was significant, $P < 0.05$.

Analyses on individuals

Regression coefficients standardized by 1 sex-specific SD for the continuous associations of food intakes with BMI are presented in **Table 3**. Among men, higher BMI was associated with lower intakes of fresh fruit, whole grains (borderline association), pasta and rice, nuts and nut butters, snacks and sweets, and alcoholic beverages along with higher intakes of fish, beef, pork, veal, and game meats; processed meats (borderline association); and carbonated soft drinks with adjustment for age, educational attainment, race-ethnicity, smoking status, history of high blood pressure or cardiovascular disease, dietary supplement use, moderate or heavy physical activity, and total energy intake. For women, higher BMI was associated with lower intake of whole grains, fish (borderline association), and snacks and sweets (borderline association) as well as higher intake of poultry, beef, pork, veal, and game meats; processed meats; and carbonated soft drinks with similar adjustment.

Energy/nutrient intakes and BMI

Ecologic analyses

Unadjusted mean values and SDs for total energy and macronutrient intakes are presented by sex and BMI category in **Table 4**; micronutrient intakes and urinary measures are presented in **Table 5**. Higher energy intake was observed across higher BMI categories in both men and women. Across higher BMI categories, higher intakes of multiple macronutrients including total fat, MUFAs, SFAs, *trans* fatty acids, and dietary cholesterol and the lowest Keys dietary lipid score (a method of expressing the qualitative lipid content of the diet) along with lower intakes of dietary fiber, total carbohydrates, and starch were observed in both men and women. Among men, higher intakes of total protein, animal protein, PUFAs, and omega-6 PUFAs; lower intakes of vegetable protein, sugars, and alcohol; and lower PUFA-to-SFA ratios were observed across higher BMI categories. In both men and women, lower intakes of several putatively favorable micronutrients (vitamins A and C, β carotene, nonheme iron, and magnesium) and higher urinary excretion of urea nitrogen (a marker of total protein intake), urinary sodium, and urinary potassium were observed across higher BMI categories. Among women, lower intakes of calcium, total iron, and phosphorus were observed across higher BMI categories, whereas a higher urinary sodium-to-potassium ratio was observed across higher BMI categories in men.

Results from the sensitivity analyses of multivariate associations between macro- and micronutrient intakes from both food and supplement sources with BMI were generally consistent in

TABLE 4

Unadjusted total energy and macronutrient intake by category of BMI in men and women (aged 40–59 y), with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	BMI (kg/m^2)					
	Men			Women		
Macronutrient	<25.0 (n = 202)	25.0–29.9 (n = 414)	≥30.0 (n = 331)	<25.0 (n = 316)	25.0–29.9 (n = 256)	≥30.0 (n = 275)
Energy (kcal/d)[2]	2567.9 ± 685.2	2613.2 ± 700.1	2712.7 ± 698.2	1828.9 ± 414.2	1870.3 ± 424.9	2054.9 ± 507.3
Dietary fiber (g/1000 kcal)[2]	9.0 ± 3.1	8.4 ± 2.8	8.1 ± 3.1	9.5 ± 3.4	9.2 ± 3.3	8.0 ± 2.8
Total protein (% kcal)[3]	14.6 ± 3.0	15.4 ± 3.1	15.6 ± 2.8	15.1 ± 3.0	15.4 ± 2.9	15.3 ± 3.0
Animal protein (% of total protein)[3]	62.2 ± 0.1	65.6 ± 0.1	67.2 ± 0.1	61.6 ± 0.1	64.6 ± 0.1	67.5 ± 0.1
Vegetable protein (% of total protein)[3]	36.2 ± 0.1	33.1 ± 0.1	31.5 ± 0.1	37.3 ± 0.1	34.4 ± 0.1	31.7 ± 0.1
Animal protein (% of energy)[3]	9.2 ± 3.0	10.2 ± 3.1	10.6 ± 2.9	9.4 ± 3.0	10.1 ± 2.9	10.4 ± 2.9
Vegetable protein (% of energy)[3]	5.2 ± 1.7	4.9 ± 1.3	4.8 ± 1.4	5.5 ± 1.5	5.2 ± 1.6	4.7 ± 1.2
Total fat (% of energy)[2]	30.9 ± 6.4	33.8 ± 5.9	34.7 ± 6.5	32.1 ± 6.6	33.2 ± 6.3	34.3 ± 6.4
MUFAs (% of energy)[2]	11.5 ± 2.8	12.5 ± 2.5	12.9 ± 2.6	11.7 ± 2.8	12.3 ± 2.7	12.7 ± 2.6
PUFAs (% of energy)[3]	6.6 ± 2.0	7.1 ± 2.0	7.0 ± 2.4	7.0 ± 2.3	7.0 ± 2.1	7.1 ± 2.1
SFAs (% of energy)[2]	9.9 ± 2.8	11.0 ± 2.5	11.4 ± 2.6	10.5 ± 2.8	10.8 ± 2.7	11.3 ± 2.6
PUFA:SFA ratio[3]	0.8 ± 0.3	0.7 ± 0.3	0.7 ± 0.3	0.8 ± 0.3	0.7 ± 0.3	0.7 ± 0.2
trans Fatty acids (% of energy)[2]	1.8 ± 0.8	2.0 ± 0.8	2.1 ± 0.8	1.9 ± 0.8	2.0 ± 0.7	2.1 ± 0.7
Omega-3 PUFAs (% of energy)	0.7 ± 0.2	0.7 ± 0.2	0.7 ± 0.3	0.8 ± 0.3	0.8 ± 0.3	0.8 ± 0.3
Omega-6 PUFAs (% of energy)[3]	6.0 ± 1.9	6.5 ± 1.9	6.4 ± 2.2	6.3 ± 2.1	6.3 ± 1.9	6.4 ± 1.9
Cholesterol[2]						
(mg/d)	309.9 ± 164.9	343.8 ± 161.5	389.6 ± 190.0	214.7 ± 96.0	248.6 ± 116.6	289.4 ± 130.0
(mg/1000 kcal)	119.2 ± 53.3	132.6 ± 57.5	141.6 ± 55.5	117.1 ± 48.6	132.9 ± 54.9	142.1 ± 60.9
Keys dietary lipid score[2,4]	33.9 ± 9.8	36.9 ± 8.8	38.8 ± 9.2	34.9 ± 9.5	36.8 ± 9.2	38.5 ± 9.0
Total carbohydrates (% of energy)[2]	50.6 ± 8.7	47.9 ± 7.4	47.3 ± 7.5	51.1 ± 7.7	49.9 ± 7.1	49.3 ± 7.5
Starch (% of energy)[2]	23.4 ± 6.7	22.4 ± 5.2	22.0 ± 5.1	23.8 ± 5.4	22.6 ± 5.5	21.9 ± 4.9
Sugars (% of energy)[3]	27.2 ± 9.4	25.6 ± 7.8	25.3 ± 8.2	27.3 ± 7.5	27.4 ± 7.4	27.4 ± 7.6
Alcohol[3]						
(g/d)	12.9 ± 19.7	11.4 ± 17.4	9.6 ± 16.3	4.0 ± 7.1	3.6 ± 6.5	3.0 ± 8.9
(% of energy)	3.8 ± 6.2	2.8 ± 4.8	2.3 ± 4.3	1.6 ± 3.7	1.3 ± 3.4	1.1 ± 3.4

[1] All values are means ± SDs. INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure.

[2] P-trend < 0.05 across BMI categories for men and women calculated by using generalized linear models with adjustment for age and race-ethnicity.

[3] P-trend < 0.05 across BMI categories for men calculated by using generalized linear models with adjustment for age and race-ethnicity.

[4] Calculated as 1.35 (2 SFA − PUFA) + 1.5 CHOL$^{1/2}$, where CHOL is dietary cholesterol in mg/1000 kcal.

TABLE 5
Unadjusted micronutrient intakes and urinary measures by category of BMI in men and women (aged 40–59 y), with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	BMI (kg/m^2)					
	Men			Women		
Micronutrient intakes and urinary measures	<25.0 (n = 202)	25.0–29.9 (n = 414)	≥30.0 (n = 331)	<25.0 (n = 316)	25.0–29.9 (n = 256)	≥30.0 (n = 275)
Vitamin A (RE/1000 kcal)[2]	3754.7 ± 2946.5	3577.8 ± 2942.4	2999.2 ± 2455.1	4464.3 ± 3962.5	4384.3 ± 3341.5	3649.0 ± 3087.3
β Carotene (μg/1000 kcal)[2]	1855.6 ± 1670.4	1731.7 ± 1735.6	1425.1 ± 1390.9	2247.9 ± 2343.0	2151.7 ± 1865.2	1735.7 ± 1727.3
Retinol (g/1000 kcal)	197.0 ± 239.4	206.0 ± 206.5	186.0 ± 215.1	213.3 ± 161.4	237.6 ± 291.8	225.3 ± 323.1
Vitamin E (mg/1000 kcal)	4.3 ± 1.6	4.5 ± 1.8	4.2 ± 1.6	4.6 ± 2.1	4.4 ± 1.3	4.4 ± 1.6
Vitamin C (mg/1000 kcal)[2]	54.6 ± 38.2	46.7 ± 29.3	44.8 ± 32.9	58.6 ± 37.3	53.7 ± 35.1	46.6 ± 30.6
Calcium (mg/1000 kcal)[3]	321.6 ± 117.7	347.2 ± 130.9	342.5 ± 130.4	389.4 ± 141.1	366.7 ± 137.5	357.4 ± 142.3
Iron (mg/1000 kcal)[3]	7.7 ± 2.7	7.7 ± 2.8	7.3 ± 2.2	8.1 ± 2.7	7.6 ± 2.1	7.2 ± 2.3
Heme iron (mg/1000 kcal)	0.5 ± 0.2	0.5 ± 0.3	0.5 ± 0.2	0.4 ± 0.2	0.5 ± 0.3	0.5 ± 0.3
Nonheme iron (mg/1000 kcal)[2]	7.3 ± 2.7	7.2 ± 2.8	6.7 ± 2.1	7.7 ± 2.7	7.2 ± 2.1	6.7 ± 2.3
Phosphorus (mg/1000 kcal)[2]	564.1 ± 122.8	578.6 ± 112.2	578.5 ± 108.7	599.5 ± 122.3	588.2 ± 117.8	570.9 ± 120.8
Magnesium (mg/1000 kcal)[2]	150.9 ± 41.0	142.8 ± 33.1	138.1 ± 34.4	157.2 ± 42.5	149.1 ± 38.5	133.7 ± 35.3
Urinary urea nitrogen (g/24 h)[2]	9.3 ± 2.5	10.8 ± 2.8	12.1 ± 3.1	7.4 ± 1.7	7.9 ± 2.0	9.0 ± 2.5
Urinary potassium (mmol/24 h)[2]	56.4 ± 19.0	64.2 ± 19.4	67.3 ± 22.6	49.6 ± 17.4	49.8 ± 17.6	50.2 ± 17.5
Urinary sodium (mmol/24 h)[2]	154.7 ± 50.8	178.5 ± 58.9	202.4 ± 63.2	127.0 ± 34.5	139.4 ± 45.2	162.5 ± 55.2
Urinary Na:K ratio[4]	3.0 ± 1.2	3.0 ± 1.1	3.3 ± 1.2	2.9 ± 1.2	3.0 ± 1.2	3.5 ± 1.3

[1] All values are means ± SDs. INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure; RE, retinol equivalents.
[2] P-trend < 0.05 across BMI categories for men and women calculated by using generalized linear models with adjustment for age and race-ethnicity.
[3] P-trend < 0.05 across BMI categories for women calculated by using generalized linear models with adjustment for age and race-ethnicity.
[4] P-trend < 0.05 across BMI categories for men calculated by using generalized linear models with adjustment for age and race-ethnicity.

direction and magnitude when compared with the analyses of nutrients from food sources only, with few exceptions. Specifically, when supplement sources of nutrients were included, associations between total iron, vitamin C, and phosphorus from both food and supplement sources with BMI were not statistically significant in men only (data not shown).

Analyses in individuals

Standardized regression coefficients for the association of energy and macronutrient intakes with BMI are presented by sex and BMI category in **Table 6**; standardized regression coefficients for the association between micronutrient intakes and urinary measures with BMI are presented in **Table 7**. Expressed per 500 kcal, higher daily energy intake was associated with higher BMI in both men and women with adjustment for age, race-ethnicity, smoking status, history of high blood pressure or cardiovascular disease, dietary supplement use, and moderate/heavy physical activity. Lower physical activity was also significantly associated with higher BMI in men after energy intake was accounted for; this association was not significant in women. Expressed per 1 sex-specific SD of residual value, higher intakes of several macronutrients were consistently associated with higher BMI in both men and women, including total protein, animal protein, total fat (borderline significant in women), MUFAs (borderline significant in women), SFAs, cholesterol, and Keys dietary lipid score. In men only, higher intakes of PUFA, *trans* fatty acids, omega-3 and omega-6 PUFAs, linoleic acid, and linolenic acid were associated with higher BMI. Lower intakes of several macronutrients were associated with higher BMI in both sexes, including dietary fiber, vegetable protein (borderline significant in both sexes), PUFA-to-SFA ratio, total carbohydrate, sugar (borderline significant in women), and alcohol (borderline significant in women).

With regard to micronutrients and urinary measures, higher intakes of heme iron and higher urinary excretion of urea nitrogen, potassium, and sodium and higher urinary sodium-to-potassium ratio were associated with higher BMI in both men and women (Table 7). Lower intakes of vitamin A (borderline association in men), vitamin C, nonheme iron (borderline significant association in women), and magnesium were associated with higher BMI. In men, lower total iron and higher phosphorus (borderline association) were associated with higher BMI, whereas lower intake of β carotene was associated with higher BMI in women (borderline association) but not in men.

DISCUSSION

This study provides population-based evidence that middle-aged US men and women who are of normal weight consume a diet composed of foods and nutrients that are different in composition from those consumed by overweight and obese persons. The leaner individuals in these 8 diverse population samples had in common a diet lower in total energy and lower in energy-dense foods (eg, meats, fats, carbonated and sugar-sweetened beverages) in comparison with diets of overweight/obese individuals. Despite the lower caloric intake, leaner individuals also exhibited higher intake of several nutrient-dense foods as well as higher intakes of vegetable protein and fiber. The dietary difference in total energy intake between lean and overweight/obese Americans may seem intuitive on the basis of the law of thermodynamics, but earlier studies reported higher calorie intake among leaner individuals perhaps reflecting a time when energy expenditure was greater among these individuals

TABLE 6
Standardized regression coefficients for associations between energy intake, physical activity, and macronutrient intake with BMI (kg/m^2) in men and women (aged 40–59 y), with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	Men (n = 947)			Women (n = 847)		
Variable	ST β	SE	P value	ST β	SE	P value
Energy (kcal/d)[2]	0.38	0.11	0.001	1.41	0.22	<0.001
Physical activity (h/d)[2]	−0.21	0.05	<0.01	−0.05	0.07	0.41
Dietary fiber (g/d)	−0.49	0.15	<0.01	−0.48	0.21	0.02
Total protein (g/d)[2]	0.76	0.15	<0.001	0.78	0.20	<0.001
Animal protein (g/d)[2]	0.85	0.15	<0.001	0.92	0.20	<0.001
Vegetable protein (g/d)	−0.31	0.16	0.05	−0.41	0.21	0.05
Total fat (g/d)[2]	0.88	0.15	<0.001	0.39	0.20	0.06
MUFAs (g/d)[2]	0.88	0.15	<0.001	0.37	0.20	0.07
PUFAs (g/d)[2]	0.36	0.15	0.02	−0.12	0.20	0.54
SFAs (g/d)[2]	0.72	0.15	<0.001	0.51	0.20	0.01
PUFA:SFA ratio	−0.32	0.16	0.04	−0.48	0.20	0.02
Cholesterol (mg/d)[2]	0.67	0.15	<0.001	0.56	0.21	<0.01
Keys dietary lipid score[3]	0.74	0.15	<0.001	0.61	0.20	<0.01
trans Fatty acids (g/d)[2]	0.42	0.15	0.01	0.11	0.20	0.60
Omega-3 PUFAs (g/d)[2]	0.42	0.15	0.01	0.04	0.20	0.84
Omega-6 PUFAs (g/d)	0.33	0.15	0.03	−0.11	0.20	0.58
Linoleic acid (g/d)[2]	0.32	0.15	0.03	−0.15	0.20	0.45
Linolenic acid (g/d)	0.34	0.15	0.02	0.16	0.20	0.43
Total carbohydrates (g/d)[2]	−0.70	0.15	<0.001	−0.45	0.20	0.02
Starch (g/d)[2]	−0.10	0.16	0.52	−0.17	0.21	0.43
Sugars (g/d)[2]	−0.64	0.15	<0.001	−0.36	0.20	0.07
Alcohol (g/d)	−0.39	0.15	0.01	−0.38	0.21	0.07

[1] Associations of nutrient intakes with BMI were assessed with linear regression by using the residual method to examine associations independent of total energy intake. Regression coefficients are presented for the residual value predicted by total energy intake and were standardized per 1-SD difference except for total energy, which is presented per 500 kcal/d (unstandardized), and physical activity, which is presented as h/d (unstandardized). All models were adjusted for age, education (y), race-ethnicity, smoking status (yes or no), history of high blood pressure or cardiovascular disease (yes or no), dietary supplement use (yes or no), moderate or heavy physical activity (h/d), and total energy intake (kcal/d). INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure; ST, standardized.

[2] Test for between-sex heterogeneity was significant, $P < 0.10$.

[3] Calculated as $1.35\ (2\ \text{SFA} - \text{PUFA}) + 1.5\ \text{CHOL}^{1/2}$, where CHOL is dietary cholesterol in mg/1000 kcal.

(16, 17). In these modern times of lower energy expenditure, increased sedentary time, and greater exposure to increased portion sizes, our results may reflect deliberate efforts by these leaner individuals to avoid obesity.

Despite the seemingly intuitive nature of these current findings, there have recently been popularized recommendations [eg, by Atkins (18) and his followers] to combat the obesity problem by consuming a diet high in protein and total fat based on the notion that metabolizing a low-carbohydrate diet promotes higher energy expenditure compared with other dietary approaches, which leads to enhanced weight loss. On the contrary, in the current study the self-selected diet among people of normal weight, despite the obesogenic environment, was higher in carbohydrate, fiber, and vegetable protein than the diet consumed by overweight/obese men and women. These population-based findings lend no support to the value of low-carbohydrate diets for maintaining normal body weight. These INTERMAP findings are also consistent with current US Dietary Guidelines for the prevention of obesity (19) and other recommendations (20, 21) that emphasize replacement of foods high in fat and sugar with carbohydrates that are lower in energy density and higher in dietary fiber—an effective strategy for enhancing satiety. However, data from a recent prospective 4-y analysis of 120,877 adults reported that intake of carbohydrates that are high in fiber with a low glycemic index are more beneficial for weight control than refined grains and potatoes (22). Although the examination of specific carbohydrate sources is outside the scope of the current investigation, the public health message regarding the intake of vegetable sources of carbohydrates may be more complex than previously considered.

Also implicit in these recommendations is that refined carbohydrate, or sugar, intake should be reduced. High intakes of both sugar-sweetened and total carbonated soft drinks were observed in the US INTERMAP participants, particularly among obese women. Carbonated soft drinks include both sugar-sweetened and nonnutritive beverages; it is possible that substantial amounts of diet soft drinks were being consumed by overweight and obese women as a weight-loss strategy. In this case, the association between carbonated soft drinks and BMI

TABLE 7
Standardized regression coefficients for association between micronutrient intake and urinary measures with BMI (kg/m^2) in men and women (aged 40–59 y), with the exclusion of participants consuming a special diet (United States, 1996–1999): the INTERMAP (n = 1794)[1]

	Men (n = 947)			Women (n = 847)		
Variable	ST β	SE	P value	ST β	SE	P value
Vitamin A (RE/d)	−0.31	0.15	0.05	−0.59	0.20	<0.01
β Carotene (μg/d)[2]	−0.26	0.15	0.10	−0.64	0.20	0.01
Retinol (μg/d)[2]	−0.20	0.15	0.18	0.14	0.20	0.47
Vitamin E (mg/d)	−0.12	0.15	0.41	−0.30	0.20	0.12
Vitamin C (mg/d)	−0.38	0.16	0.02	−0.44	0.20	0.03
Calcium (mg/d)	0.06	0.16	0.70	0.27	0.22	0.21
Iron (mg/d)	−0.39	0.15	0.01	−0.29	0.21	0.16
Heme iron (mg/d)[2]	0.52	0.15	0.01	0.63	0.20	<0.01
Nonheme iron (mg/d)	−0.46	0.15	0.01	−0.39	0.21	0.06
Phosphorus (mg/d)[2]	0.29	0.15	0.06	0.34	0.21	0.11
Magnesium (mg/d)	−0.44	0.16	0.01	−0.49	0.22	0.03
Urinary urea nitrogen (g/24 h)[2]	1.63	0.15	<0.001	1.97	0.19	<0.001
Urinary potassium (mmol/24 h)	0.85	0.17	<0.001	0.54	0.22	<0.01
Urinary sodium (mmol/24 h)[2]	1.27	0.15	<0.001	1.44	0.19	<0.001
Urinary Na:K ratio[2]	0.54	0.16	0.01	0.66	0.22	<0.01

[1] Associations of nutrient intakes and urinary measures with BMI were assessed with linear regression by using the residual method to examine associations independent of total energy intake. Regression coefficients are presented for the residual value as predicted by total energy intake and were standardized per 1-SD difference. All models were adjusted for age, education (y), smoking status (yes or no), history of high blood pressure or cardiovascular disease (yes or no), dietary supplement use (yes or no), moderate or heavy physical activity (h/d), and total energy intake (kcal). INTERMAP, International Study of Macro-/Micronutrients and Blood Pressure; RE, retinol equivalents; ST, standardized.

[2] Test for between-sex heterogeneity was significant, $P < 0.10$.

would reflect reverse causation. However, the borderline positive association between sugar-sweetened beverages (excluding diet soft drinks) and BMI could well be a reflection of direct causation.

A major strength of this study is that intakes of both foods and nutrients were examined on the basis of high-quality, standardized, extensive macro- and micronutrient data from 8 diverse US population INTERMAP samples. These data were derived from 4 in-depth 24-h dietary recalls per person collected by trained, standardized, and certified interviewers and immediately computerized by using comprehensive high-quality comparable databases of the Nutrition Coordinating Center system (13, 15). Also, this approach allowed comparison of individual energy intakes with precision, which is not achievable with abbreviated food-frequency assessment methods. Timed 24-h urine collections provided objective biomarkers that allowed further comparisons of nutrient intake that complemented and enhanced the accuracy of the self-reported dietary assessment data.

Limitations of this study include its cross-sectional design. No data are available over time to examine whether physical activity, energy, or nutrient intakes directly relate prospectively to BMI. Reverse causation is a particular concern when assessing associations with body weight in a cross-sectional setting because an individual's perception of his or her weight status may influence dietary or other lifestyle behavior, producing spurious associations. Because overweight and obese individuals may increase physical activity subsequent to weight gain in efforts to lose weight, the potential for reverse causation could specifically explain the lack of association between physical activity and BMI observed in women. Physical activity and dietary intakes were also self-reported, raising the possibility of inaccurate or biased participant recall. Finally, the INTERMAP sample size was relatively small compared with other population-based observational investigations. This study was originally designed to assess relations between dietary intake and blood pressure; it is limited when used to address the causes of obesity. Nonetheless, these findings provide evidence for possibly effective approaches for obesity prevention and management on a population basis.

In conclusion, these data—examined both ecologically and individually—show that free-living normal-weight US adults consumed diets lower in total energy and higher in nutrient-dense foods (eg, fresh fruit, whole grains, and pasta and rice) compared with overweight individuals. Lean participants had lower intakes of meats, fats, sugar-sweetened beverages, carbonated drinks, and nonalcoholic beverages. Their diets were consequently higher in many macro- and micronutrients (vegetable protein, dietary fiber, carbohydrates, vitamin A and C, magnesium, and nonheme iron) and lower in animal protein, fats, dietary cholesterol, and sodium. These findings indicate that lower BMI in the US middle-aged population is associated with more favorable food and nutrient intakes resulting in overall better dietary quality. The corresponding unfavorable dietary patterns exhibited among obese individuals may be responsible, at least in part, for the higher morbidity and mortality observed in this population stratum (21, 23–30). The promotion of population-wide intakes of more nutrient-dense foods—through encouragement of self-selection and systematic improvements in the population food supply—could provide substantial public health benefits.

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