Trends in carbohydrate, fat, and protein intakes and association with energy intake in normal-weight, overweight, and obese individuals: 1971–2006[1–3]

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ABSTRACT

Background: The prevalence of obesity in the United States has increased dramatically.

Objective: The aim of this study was to determine trends in carbohydrate, fat, and protein intakes in adults and their association with energy intake by using data from the National Health and Nutrition Examination Survey (NHANES)—a representative sample of the US population.

Design: Data on adults aged 20–74 y from the first NHANES (NHANES I, 1971–1975; n = 13,106) were compared with data from NHANES 2005–2006 (n = 4381). Normal weight was defined as a body mass index (BMI; in kg/m^2) of 19 to <25, overweight as a BMI of 25 to <30, and obese as a BMI of ≥30. Carbohydrate, fat, and protein intakes were obtained by dietary recall. Regression analyses were adjusted for potential confounders.

Results: The prevalence of obesity increased from 11.9% to 33.4% in men and from 16.6% to 36.5% in women. The percentage of energy from carbohydrates increased from 44.0% to 48.7%, the percentage of energy from fat decreased from 36.6% to 33.7%, and the percentage of energy from protein decreased from 16.5% to 15.7%. Trends were identical across normal-weight, overweight, and obese groups. Energy intake increased substantially in all 3 BMI groups. In NHANES 2005–2006, a 1% increase in the percentage of energy from protein was associated with a decrease in energy intake of 32 kcal (substituted for carbohydrates) or 51 kcal (substituted for fat). Similar findings were seen across all BMI categories, in men and women, and in NHANES I.

Conclusions: Energy intake and the prevalence of obesity have increased dramatically. Dietary interventions should focus on decreasing energy intake and potentially by substituting protein for fat or carbohydrates. *Am J Clin Nutr* 2011;93:836–43.

INTRODUCTION

The increasing prevalence of obesity has been well documented (1, 2). According to the National Health and Nutrition Examination Survey (NHANES), the prevalence of obesity among adults aged 20–74 y has increased from 11.9% in men and 16.6% in women during NHANES I (1971–1975) to 31.1% in men and 33.2% in women based on data from NHANES 2003–2004 (1). The energy content of food is derived from macronutrients (carbohydrate, fat, and protein), and there has been a consistent emphasis over the past 4 decades to reduce the proportion of energy from fat. However, the evidence to support the recommendation that decreasing the percentage of energy from fat in the diet will translate into an effective method of reducing the prevalence of obesity is controversial (3, 4).

A previously published report examined obesity and macronutrient trends from NHANES and reported that the percentage of energy from carbohydrates increased, whereas the percentage of energy from fat and protein decreased during the period from 1971 to 2000 (5). However, they did not evaluate whether trends in macronutrient intake were similar across normal-weight, overweight, and obese groups. They also did not evaluate the association between macronutrient distribution and total energy intake across these 3 groups. The purpose of this study was to examine trends in carbohydrate, fat, and protein intakes among adults and their association with energy intake among normal-weight, overweight, and obese men and women.

SUBJECTS AND METHODS

Population

Prevalence estimates for the normal-weight, overweight, and obese individuals were calculated by using data from NHANES. NHANES is a program of studies designed to assess the health and nutritional status of adults and children in the United States and represents a complex multistage probability sample of the US civilian, noninstitutionalized population (6). The NHANES program began in the 1960s and periodically conducted separate surveys. Since 1999, NHANES has been conducted continuously in 2-y cycles. Data from NHANES I (1971–1975) and from NHANES 2005–2006 were obtained to evaluate time trends. Demographic, socioeconomic, and dietary data are collected as part of the interview. For both NHANES cohorts, physical examinations were performed in a mobile examination center, where height and weight were measured by using standardized

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protocols and calibrated equipment, and body mass index (BMI) was calculated in kg/m^2. Data from 13,106 adults aged 20–74 y were available from NHANES I, and data from 4381 adults aged 20–74 y were available from NHANES 2005–2006. We excluded pregnant women from both NHANES I and NHANES 2005–2006. In calculating total calories as well as the macronutrient distribution, we excluded individuals who had recent changes to their diet. For NHANES I, we excluded individuals (n = 3337) who answered "yes" to the question of "Has your diet changed recently?" For NHANES 2005–2006, we excluded individuals (n = 657) who answered "yes" to the question "Are you currently on any kind of diet, either to lose weight or for some other health-related reason?"

Assessment of dietary intake

For NHANES I, an interview was conducted by trained staff at study entry. A 24-h dietary recall questionnaire was completed by the participants, which collected the specific food items and quantities consumed by each participant from midnight to midnight on the day preceding the in-person interview. For NHANES I, the method used accounted for all regular meals and between-meal foods and snacks eaten on Monday through Friday, but excluded food eaten on the weekends. Three-dimensional food models were used as aids in estimating quantities consumed. Total grams of carbohydrate, fat, protein, and alcohol were calculated by entering the data from the 24-h dietary recall into a Nutrient Composition Data Bank.

For NHANES 2005–2006, all participants were asked to complete two 24-h dietary recall interviews. For both dietary recall interviews, all food items and quantities consumed by each participant from midnight to midnight on the day preceding the interview were recorded. The first dietary recall interview was collected in-person. The second interview was collected by telephone 3–10 d later, although not on the same day of the week as the in-person interview. The dietary recalls for NHANES 2005–2006 used the Automated Multiple Pass Method (7), which is designed to increase the efficiency and accuracy of the 24-h recall by including a thorough compilation of standardized food-specific questions and possible responses. A set of measuring guides were given to participants for help in reporting food amounts during the in-person interview. These guides and a food-model booklet were given to the participants to assist in reporting food amounts during the subsequent telephone interview. The 24-h recalls included both weekdays and weekend days. Data from the two 24-h recalls were averaged to produce an estimate of the grams of carbohydrates, fat, protein, and alcohol consumed by each participant.

Outcomes

Individuals were classified into normal-weight, overweight, and obese on the basis of their BMI. For adults in both NHANES I and NHANES 2005–2006, normal weight was defined as a BMI (in kg/m^2) of 19.0 to $<$25.0, overweight was defined as a BMI of 25.0 to $<$30.0, and obese was defined as a BMI of $\geq$30.0. The distribution of energy intake for each individual was calculated on the basis of data obtained during the dietary interview. For NHANES 2005–2006, 2 separate dietary recalls were performed, and the results from the 2 d were averaged. Outcomes were the percentage of energy intake from each macronutrient (carbohydrate, fat, and protein) and total energy intake. Additional outcomes included the associations between the percentage of energy intake from each macronutrient and daily energy intake.

Statistical analyses

Statistical analyses were performed by using Stata software (version 10.0; StataCorp, College Station, TX). We used the appropriate survey commands in STATA and applied the recommended sample weights for the data to account for unequal probabilities of selection. Means ($\pm$SE) for percentages and total energy from carbohydrates, fat, and protein were calculated for men and women separately for the normal-weight, overweight, and obese groups. All analyses excluded pregnant women. In multivariable models, we adjusted for age, sex, educational status, alcohol consumption, and race-ethnicity. Age was modeled by using a quadratic polynomial, which provided the best fit to the data. Educational status was dichotomized into those who had attended some college (including those who had graduated) and those who did not have any education beyond the high school level (including those who had not finished high school). Race-ethnicity was also dichotomized into white and nonwhite for both NHANES I and NHANES 2005–2006 as NHANES I did not separately track the Hispanic population. Alcohol consumption was included as the percentage of energy from alcohol.

Linear regression was used to assess the relation between the percentage of energy from each macronutrient and total energy intake adjusted for the above covariates and the percentage of energy from the other major sources of energy. Interaction terms between each pair of macronutrients were included in the model, which allowed the effect of increasing the percentage of energy from one macronutrient to vary based on the levels of other macronutrients. This model is known as Scheffe's Quadratic Canonical Polynomial Model, which can be used to model compositional or mixture data (8). We also tested for interactions between macronutrient intake and sex and age. These interaction terms were not significant and were not included in the final model. On the basis of the results of the regression models, we calculated the predicted energy intake across different ranges of percentages of energy from protein, varying the percentage of energy from carbohydrate and fat accordingly. At the average macronutrient composition (47% carbohydrates, 35% fat, 15% protein, and 3% alcohol), we report the incremental change in energy intake for a 1% increase in the percentage of energy from protein exchanged for carbohydrate or fat in NHANES I and NHANES 2005–2006. Models were also fit separately for each of the 3 BMI categories.

RESULTS

Trends in energy intake and BMI

Select demographic characteristics of the NHANES I and NHANES 2005–2006 study populations are presented in **Table 1**. Compared with data from NHANES I, the prevalence of obesity among adults aged 20–74 y dramatically increased from 11.9% to 33.4% in men and from 16.6% to 36.5% in women.

TABLE 1
Demographic and educational characteristics of normal-weight, overweight, and obese adults aged 20–74 y from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) and NHANES 2005–2006

	Normal weight	Overweight	Obese	*P* value[1]
NHANES I				
n	6149	4046	2081	
Age (y)	41.6 ± 0.4[2]	45.8 ± 0.4	47.3 ± 0.5	<0.001
Race (% white)	90.8 ± 0.8	91.2 ± 0.8	86.4 ± 1.5	0.004
Women (%)	55.2 ± 0.9	34.6 ± 1.4	56.9 ± 2.0	<0.001
Completed some college (%)	33.1 ± 1.3	28.7 ± 1.6	18.5 ± 1.7	<0.001
NHANES 2005–2006				
n	1121	1416	1520	
Age (y)	40.5 ± 0.7	44.5 ± 0.9	45.6 ± 0.7	<0.001
Race (% white)	73.7 ± 2.0	69.6 ± 3.4	68.4 ± 3.6	0.257
Women (%)	56.8 ± 2.2	35.4 ± 1.6	49.6 ± 2.6	<0.001
Completed some college (%)	60.5 ± 3.6	58.5 ± 2.9	52.1 ± 1.7	0.118

[1] *P* values for the overall *F* test for each variable from linear regression.
[2] Mean ± SEM (all such values).

The proportion of men who were either overweight or obese increased from 52.9% to 73.6%, whereas the proportion of women who were either overweight or obese increased from 40.7% to 61.5%. The proportion of men who were of normal weight decreased from 43.7% to 24.6%, and the proportion of women who were of normal-weight decreased from 51.4% to 35.3%. Compared with NHANES I, men consumed an additional 179 ± 51 kcal/d, whereas women consumed an additional 199 ± 32 kcal/d. Daily energy intake increased among normal-weight, overweight, and obese individuals (**Figure 1**). Compared with NHANES I, normal-weight men consumed an additional 247 kcal, overweight men consumed an additional 165 kcal, and obese men consumed an additional 225 kcal based on NHANES 2005–2006 data (**Table 2**). Compared with NHANES I, normal-weight women consumed an additional 183 kcal, overweight women consumed an additional 304 kcal, and obese women consumed an additional 341 kcal (Table 2).

Minimal increases in height were observed among men and women (1.2 ± 0.3 and 1.0 ± 0.3 cm, respectively) from NHANES I to NHANES 2005–2006. Consequently, mean weights would be expected to be higher within each BMI category. Indeed, normal-weight men and women weighed an additional 1.6 ± 0.6 and 1.5 ± 0.4 kg, respectively, in NHANES 2005–2006 compared with NHANES I. Overweight men and women weighed an additional 2.3 ± 0.5 and 2.1 ± 0.5 kg, respectively. Finally, obese men and women weighed an additional 8.2 ± 1.0 and 7.4 ± 1.1 kg, respectively. Overall, the percentage of energy from alcohol decreased in men (from 4.3% to 3.0%) and in women (from 1.7% to 0.8%).

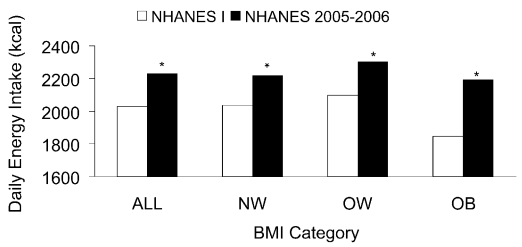

FIGURE 1. Trends in energy intake from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) to NHANES 2005–2006 in normal-weight (NW), overweight (OW), obese (OB), and all (ALL) individuals. *Significantly different from NHANES I, $P < 0.001$.

Trends in energy intake and macronutrient distribution

Carbohydrates

The percentage of energy from carbohydrates increased uniformly across both men and women and across the normal-weight, overweight, and obese groups (**Figure 2**). In NHANES I, the percentage of energy from carbohydrates was 45.2% for normal-weight women, 45.3% for overweight women, and 45.9% for obese women (Table 2). In NHANES 2005–2006, the percentage of energy from carbohydrates was 49.9% for normal-weight women, 49.5% for overweight women, and 49.3% for obese women. Men had a modestly lower percentage of energy from carbohydrates than did women in both NHANES I and NHANES 2005–2006, but the trends were identical. In NHANES I, the percentage of energy from carbohydrates was 43.1% for normal-weight men, 42.2% for overweight men, and 41.0% for obese men. In NHANES 2005–2006, the percentage of energy from carbohydrates was 47.8% for normal-weight men, 48.2% for overweight men, and 47.3% for obese men. In a comparison of NHANES 2005–2006 with NHANES I, men had an increased absolute daily carbohydrate intake (by 220 ± 21 kcal, from 1049 to 1268 kcal), and women had an increased absolute daily carbohydrate intake (by 166 ± 14 kcal, from 721 to 887 kcal).

Fat

The percentage of energy from fat decreased uniformly across both men and women and across the normal-weight, overweight, and obese groups (**Figure 3**). In NHANES I, the percentage of energy from fat was 36.5% for normal-weight women, 36.2% for overweight women, and 35.9% for obese women (Table 2). In NHANES 2005–2006, the percentage of energy from fat was 33.2% for normal-weight women, 34.3% for overweight women, and 34.5% for obese women. The trends were identical in men. In NHANES I, the percentage of energy from fat was 37.0% for normal-weight men, 36.4% for overweight men, and 37.5% for obese men. In NHANES 2005–2006, the percentage

TABLE 2
Comparison of dietary composition and total energy intake in men and women from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) and NHANES 2005–2006 in normal-weight, overweight, and obese groups

	NHANES I				NHANES 2005–2006			
	Normal weight	Overweight	Obese	*P* value[1]	Normal weight	Overweight	Obese	*P* value[1]
Men								
n	2181	2004	612		475	808	643	
Carbohydrate (% of energy)	43.1 ± 0.4[2]	42.2 ± 0.4	41.0 ± 0.6	0.02	47.8 ± 0.5	48.2 ± 0.7	47.3 ± 0.4	0.43
Fat (% of energy)	37.0 ± 0.3	36.4 ± 0.4	37.5 ± 0.5	0.28	33.3 ± 0.5	33.3 ± 0.4	34.5 ± 0.2	<0.01
Protein (% of energy)	15.9 ± 0.2	16.7 ± 0.2	17.4 ± 0.3	<0.01	15.4 ± 0.2	15.5 ± 0.2	15.9 ± 0.3	0.42
Total daily energy intake (kcal)	2551 ± 37	2416 ± 37	2384 ± 41	<0.01	2798 ± 45	2581 ± 48	2608 ± 63	<0.01
Women								
n	3968	2042	1469		646	608	877	
Carbohydrate (% of energy)	45.2 ± 0.3	45.3 ± 0.4	45.9 ± 0.7	0.56	49.9 ± 0.5	49.5 ± 0.5	49.3 ± 0.5	0.74
Fat (% of energy)	36.5 ± 0.2	36.2 ± 0.3	35.9 ± 0.5	0.40	33.2 ± 0.4	34.3 ± 0.5	34.5 ± 0.5	0.08
Protein (% of energy)	16.4 ± 0.2	16.9 ± 0.2	17.2 ± 0.3	0.01	15.4 ± 0.2	15.6 ± 0.2	16.2 ± 0.3	0.23
Total daily energy intake (kcal)	1626 ± 20	1492 ± 24	1446 ± 29	<0.01	1809 ± 40	1796 ± 41	1787 ± 42	0.94

[1] *P* values for the overall *F* test for each variable from linear regression.
[2] Mean ± SEM (all such values).

of energy from fat was 33.3% for normal-weight men, 33.3% for overweight men, and 34.5% for obese men. In a comparison of NHANES 2005–2006 with NHANES I, men had a decreased absolute daily fat intake (by 20 ± 23 kcal, from 909 to 889 kcal), whereas women had an increased absolute daily fat intake (by 27 ± 14 kcal, from 577 to 605 kcal). The percentage of energy from saturated fat intake was significantly lower in normal-weight (13.4 ± 0.1% compared with 11.1 ± 0.1%), overweight (13.1 ± 0.1% compared with 11.2 ± 0.1%), and obese (13.2 ± 0.2% compared with 11.5 ± 0.1%) individuals in NHANES 2005–2006 than in NHANES I. Similarly, cholesterol intake (mg/d) was significantly lower in normal-weight (393.9 ± 8.1 mg compared with 286.2 ± 7.0 mg), overweight (422.9 ± 8.7 mg compared with 301.8 ± 6.4 mg), and obese (397.3 ± 11.9 mg compared with 305.4 ± 7.4 mg) individuals in NHANES 2005–2006 than in NHANES I. Data for total intake of monounsaturated and polyunsaturated fats were not available for NHANES I.

Protein

The percentage of energy from protein decreased across both men and women and across the normal-weight, overweight, and obese groups (**Figure 4**). In NHANES I, the percentage of energy from protein was 16.4% for normal-weight women, 16.9% for overweight women, and 17.2% for obese women (Table 2). In NHANES 2005–2006, the percentage of energy from protein was 15.4% for normal-weight women, 15.6% for overweight women, and 16.2% for obese women. Similar declines in the percentage of energy from protein occurred in men. In NHANES I, the percentage of energy from protein was 15.9% for normal-weight men, 16.7% for overweight men, and 17.4% for obese men. In NHANES 2005–2006, the percentage of energy from protein was 15.4% for normal-weight men, 15.5% for overweight men, and 15.9% for obese men. In a comparison of NHANES 2005–2006 with NHANES I, men increased their absolute daily protein intake by 7 ± 9 kcal (from 404 to 412 kcal), and women increased their absolute daily protein intake by 19 ± 7 kcal (from 263 to 282 kcal).

Association of macronutrient distribution with energy intake

Consumption of a higher percentage of energy from protein with a corresponding reduction in either the percentage of energy from fat or carbohydrates was strongly associated with reduced energy intake in both NHANES I and NHANES 2005–2006 across all BMI categories (**Figure 5**). Because there was some minor variation in the effect of protein content on energy intake

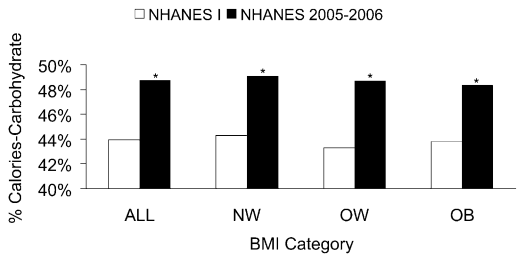

FIGURE 2. Trends in the percentage of energy from carbohydrates from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) to NHANES 2005–2006 in normal-weight (NW), overweight (OW), obese (OB), and all (ALL) individuals. *Significantly different from NHANES I, $P < 0.001$.

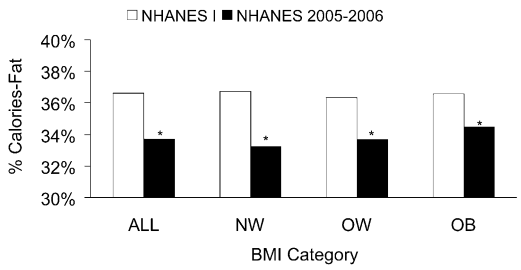

FIGURE 3. Trends in the percentage of energy from fat from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) to NHANES 2005–2006 in normal-weight (NW), overweight (OW), obese (OB), and all (ALL) individuals. *Significantly different from NHANES I, $P < 0.001$.

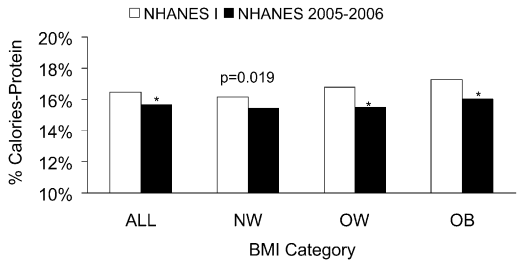

FIGURE 4. Trends in the percentage of energy from protein from the first National Health and Nutrition Examination Survey (NHANES I, 1971–1975) to NHANES 2005–2006 in normal-weight (NW), overweight (OW), obese (OB), and all (ALL) individuals. *Significantly different from NHANES I, $P < 0.001$.

across the range of reasonable percentages of energy from fat and carbohydrates (**Figure 6**), the estimates for the change in daily energy intake assumed a baseline macronutrient intake of 47% carbohydrates, 35% fat, and 15% protein. The model for NHANES I predicted that a 1% increase in the percentage of energy from protein with a corresponding 1% decrease in the percentage of energy from carbohydrates resulted in a decrease in daily energy intake of 16 kcal in normal-weight individuals ($P = 0.001$; 95% CI: −25, −6 kcal), 25 kcal in overweight individuals ($P < 0.001$; 95% CI: −35, −15 kcal), and 12 kcal in obese individuals ($P = 0.192$; 95% CI: −30, 6 kcal:). The decrease in energy intake associated with the substitution of protein for carbohydrates was more pronounced in NHANES 2005–2006. The model for NHANES 2005–2006 predicted that a 1% increase in the percentage of energy from protein with a corresponding 1% decrease in the percentage of energy from carbohydrates resulted in a decrease in daily energy intake of 33 kcal in normal-weight individuals ($P = 0.004$; 95% CI: −54, −12 kcal), 31 kcal in overweight individuals ($P = 0.007$; 95% CI: −52, −10 kcal), and 33 kcal in obese individuals ($P = 0.001$; 95% CI: −50, −17 kcal).

Even more striking results were seen with the substitution of protein for fat. In NHANES I, a 1% increase in the percentage of energy from protein with a corresponding 1% decrease in the percentage of energy from fat resulted in a decrease in daily energy intake of 38 kcal in normal-weight individuals ($P < 0.001$; 95% CI: −49, −27 kcal), 43 kcal in overweight individuals ($P < 0.001$; 95% CI: −55, −31 kcal), and 45 kcal in obese individuals ($P < 0.001$; 95% CI: −69, −21 kcal). The decrease in energy intake associated with the substitution of protein for fat was more pronounced in NHANES 2005–2006. The model for NHANES 2005–2006 predicted that a 1% increase in the percentage of energy from protein with a corresponding 1% decrease in the percentage of energy from fat resulted in a decrease in daily energy intake of 49 kcal in normal-weight individuals ($P < 0.001$; 95% CI: −72, −26 kcal), 50 kcal in overweight individuals ($P < 0.001$; 95% CI: −71, −30 kcal), and 54 kcal in obese individuals ($P < 0.001$; 95% CI: −76, −33 kcal).

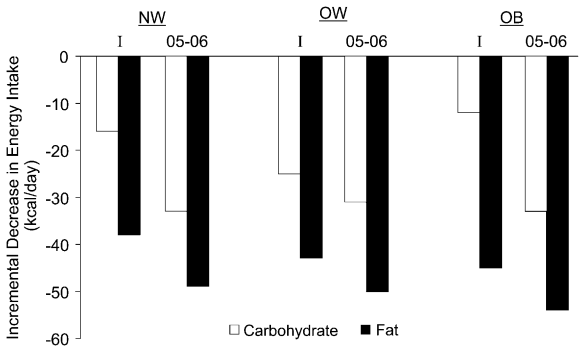

FIGURE 5. Decrease in energy intake for a 1% increase in the percentage of energy from protein substituted for a 1% decrease in the percentage of energy from carbohydrate (all $P < 0.01$) or fat (all $P < 0.001$) in normal-weight (NW), overweight (OW), and obese (OB) adults from the first National Health and Nutrition Examination Survey (NHANES I) and NHANES 2005–2006 (assuming a baseline macronutrient intake of 47% carbohydrates, 35% fat, and 15% protein).

A decrease in energy intake associated with the substitution of carbohydrates for fat was also observed. In NHANES I, a 1% increase in the percentage of energy from carbohydrates with a corresponding 1% decrease in the percentage of energy from fat resulted in a decrease in daily energy intake of 23 kcal in normal-weight individuals ($P < 0.001$; 95% CI: −27, −19 kcal), 18 kcal in overweight individuals ($P < 0.001$; 95% CI: −24, −12 kcal), and 35 kcal in obese individuals ($P < 0.001$; 95% CI: −46, −23 kcal). The decrease in energy intake associated with the substitution of carbohydrate for fat was still significant in NHANES 2005–2006. The model for NHANES 2005–2006 predicted that a 1% increase in the percentage of energy from carbohydrates with a corresponding 1% decrease in the percentage of energy from fat resulted in a decrease in daily energy intake of 16 kcal in normal-weight individuals ($P < 0.001$; 95% CI: −23, −9 kcal), 21 kcal in overweight individuals ($P < 0.001$; 95% CI: −28, −13 kcal), and 22 kcal in obese individuals ($P = 0.003$; 95% CI: −35, −8 kcal).

To understand the clinical effect of making a significant change in diet composition, we calculated changes in the predicted energy intake if the proportion of energy from protein was increased from 15% to 25% at the expense of a commensurate 10% decrease in carbohydrate or fat content. An increase in the protein content to 25% and a decrease in the carbohydrate content to 37% (and fat content remained at 35%) in the NHANES I population predicted a decrease in energy intake of 146 (95% CI: −210, −82) kcal in normal-weight individuals, of 155 (95% CI: −238, 72:) kcal in overweight individuals, and of 197 (95% CI: −340, −53) kcal in obese individuals. Per the model derived from the NHANES 2005–2006 population, an increase in the protein content to 25% and a decrease in the carbohydrate content to 37% predicted a decrease in energy intake of 386 (95% CI: −663, −110) kcal in normal-weight individuals, of 478 (95% CI: −698, −259) kcal in overweight individuals, and of 438 (95% CI: −610, −266) kcal in obese individuals. An increase in the protein content to 25% and a decrease in the fat content to 25% (and carbohydrate content remained at 47%) in the NHANES I population predicted a decrease in energy intake of 337 (95% CI: −443, −231) kcal in normal-weight individuals, of 383 (95% CI: −486, −279) kcal in overweight individuals, and of 338 (95% CI: −473, −203) kcal in obese individuals. Per the model derived from the NHANES 2005–2006 population, an increase in the protein content to 25% and a decrease in the fat content to 25% predicted a decrease in energy intake of 627 (95% CI: −860, −393) kcal in normal-weight individuals, of 635 (95% CI: −823, 446) kcal in overweight individuals, and of 620 (95% CI: −799, −442) kcal in obese individuals.

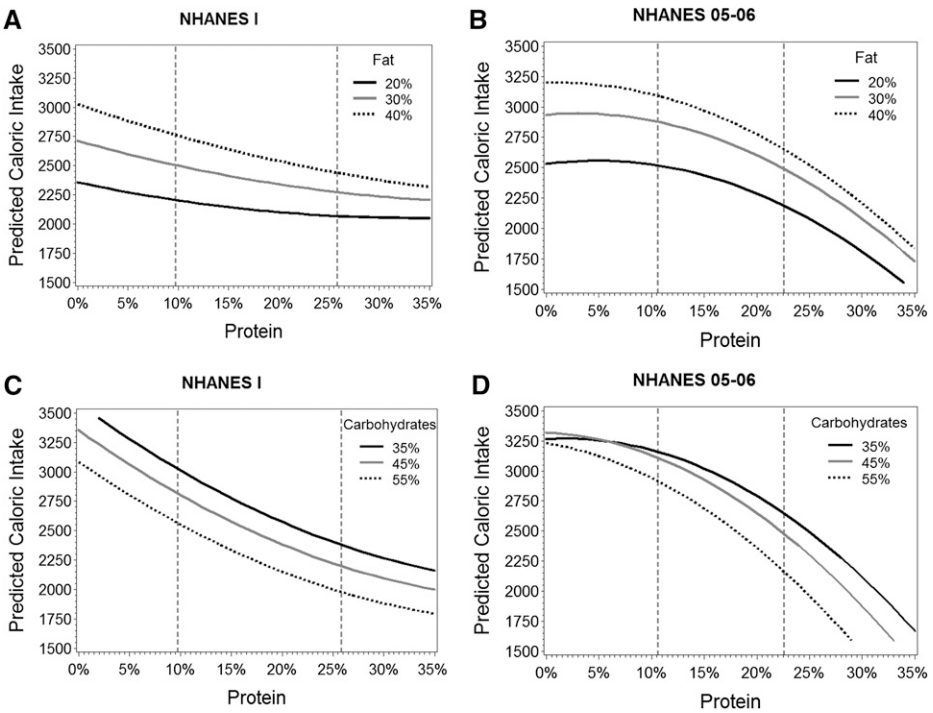

FIGURE 6. Effect of an increasing percentage of energy from protein on predicted daily energy intake. A–D: Effect of an increasing percentage of energy from protein with a commensurate reduction in carbohydrate intake for different amounts of fat intake in the first National Health and Nutrition Examination Survey (NHANES I) (A) and NHANES 2005–2006 (B) and with a commensurate reduction in fat intake for different amounts of carbohydrate intake in NHANES I (C) and NHANES 2005–2006 (D). The vertical lines represent the 5th and 95th percentiles of the percentage of energy from protein. All models assume that 3% of energy is from alcohol.

DISCUSSION

The prevalence of obesity has increased from 11.9% to 33.4% in men and from 16.6% to 36.5% in women based on a comparison of NHANES I (1971–1975) with NHANES 2005–2006 data. This increase in obesity has occurred despite messages to the public to change dietary intakes. For example, consensus efforts to lower dietary fat did lead to decreases in the percentage of energy consumed from fat. However, the reduction in the percentage of energy from fat resulted not from a significant decrease in total fat intake but rather from an increase in carbohydrate intake resulting in an increase in total energy intake. Americans have increased the percentage of energy from carbohydrates from 44.0% to 48.7%, which occurred in association with the significant increase in energy intake. Because these dietary changes did not lead to lower total energy intakes, it is not surprising that they have had little effect on the reduction of obesity in the United States. The results of our study are consistent with those of a previously published report that examined obesity and macronutrient trends from NHANES through the year 2000 (5). However, they did not stratify energy intake and macronutrient distribution across BMI groups and did not evaluate the association between the percentage of energy from each macronutrient and total energy intake.

The role of dietary fat in the development of obesity remains controversial (4, 9, 10). There is considerable interest in understanding the role that carbohydrates may play in obesity, particularly given recent randomized controlled trials suggesting that low-carbohydrate diets (which are high in fat and protein) are equivalent and occasionally superior to standard high-carbohydrate, low-fat diets in achieving weight loss (11–15). Of primary concern regarding carbohydrate consumption is the intake of sugar in the form of sucrose or high-fructose corn syrup. These sugars represent the energy source of carbonated soft drinks, the consumption of which has increased substantially since NHANES I (16). However, it is unclear to what extent carbohydrate consumption other than sugar intake has increased.

The increasing amount of energy consumed by Americans has likely contributed to the increased prevalence of obesity. Obese men and women in the United States consumed an additional 225 and 341 kcal, respectively, in NHANES 2005–2006 than in NHANES I. Interestingly, despite similar body sizes, overweight men and women consumed an additional 165 and 304 kcal, respectively, in NHANES 2005–2006 than in NHANES I. Similar trends were seen in normal-weight men and women, who consumed an additional 247 and 183 kcal, respectively. It is certainly possible that nutrient data from NHANES I may have underestimated energy intake because the method used to collect dietary data was different from that used in NHANES 2005–2006, which may have overestimated the real increase in energy intake and shifts in macronutrient composition. However, the prevalence of obesity has increased dramatically since the 1970s in parallel with significant increases in portion sizes and in the consumption of sweetened beverages (16, 17). Furthermore, the past few decades have seen a proliferation in the consumption of snack foods, including those that are low in fat (18, 19). Therefore, it is very likely that absolute energy and carbohydrate intakes have increased substantially. Furthermore, although the percentage of energy from fat has decreased, the total amount of fat consumed has not decreased in the setting of an overall increase in energy

intake, primarily from carbohydrates. Even normal-weight men and women consume at least 33% of calories from fat, which could be considered a high-fat diet as absolute fat intake has not decreased but the proportion is smaller because of the overall increase in energy intake (20). The additional calories from carbohydrates combined with a high-fat diet may only further the propensity toward obesity.

One of the most striking findings of this study was the consistently strong and negative association with increasing percentage calories from protein and daily energy intake across all 3 BMI categories in both NHANES I and NHANES 2005–2006. This finding is all the more interesting given the exclusion of individuals following any type of special diet (such as low-carbohydrate or high-protein diets) and supports human experimental data in obese individuals that a high-protein diet can be more effective at increasing satiety, reducing hunger and energy intake, and achieving greater weight loss (21–23). The decrease in energy intake was greater if protein was substituted for fat, but the effect was still substantial when protein was substituted for carbohydrates. On the basis of the associations seen in NHANES 2005–2006, if protein was increased from 15% to 25% of energy intake in an obese individual, this would be expected to be associated with a decrease in energy intake of 438 calories (if substituted for carbohydrates) or 620 calories (if substituted for fat). The association is seen consistently across normal-weight, overweight, and obese adults in both NHANES I and NHANES 2005–2006. Interestingly, the magnitude of the decrease in energy intake associated with increasing percentage calories from protein (substituted for either carbohydrates or fat) has increased from NHANES I to NHANES 2005–2006 in all 3 BMI categories. The reasons for this are not entirely clear but may represent increasing consumption of calorically dense foods that are high in carbohydrates (particularly those high in sugar), high in fat, or both.

There are clear limitations to the results presented in this study. First, the NHANES data were obtained as a cross-sectional survey. Therefore, it is impossible to determine whether dietary patterns assessed represented the usual dietary pattern over an individual's life that led to their weight status at the time of the examination, particularly for those who are obese. However, it is less likely that normal-weight individuals would need to change their dietary pattern, and the trends in total energy intake and macronutrient distribution are similar across the normal-weight, overweight, and obese groups. There are issues related to the validity in which dietary recalls are performed, primarily the underreporting of food intake and that participants may change their usual dietary pattern because they are part of a study (24). Obese individuals may be more likely to underreport food intake and specifically fat intake, which certainly could alter the macronutrient composition of their diet as well as total energy intake (7, 25). Another limitation is that a direct comparison of sugar intake between the 2 surveys is not possible. Although sugar intake is separately calculated (and represents 22.7% of total energy intake) currently as part of NHANES, it was not separately recorded as part of NHANES I. Therefore, it is unclear how much of the increase in carbohydrate intake is due to an increase in sugar intake compared with an increase in complex carbohydrate intake. Nevertheless, the overall trends of increasing energy intake, increasing proportion of calories from carbohydrates, and decreasing percentage of calories from fat and protein is consistently seen across normal-weight, overweight, and obese groups. Finally, we chose to exclude individuals who reported having changed their diet recently (NHANES I) or who were following a special diet (NHANES 2005–2006) to minimize the effect that cognitive restraint may have had on total energy intake and macronutrient distribution. However, the trends in macronutrient distribution among those who were excluded were similar between NHANES I and NHANES 2005–2006, except that those excluded from the NHANES 2005–2006 dataset consumed far fewer calories from alcohol and had a modest increase in percentage calories from protein compared with those excluded from the NHANES I data set. For individuals excluded from both NHANES I and NHANES 2005–2006, the negative association between percentage of calories from protein and energy intake was identical to the results reported for those who met inclusion criteria.

In conclusion, the public health implications of obesity are enormous. It is important to understand whether macronutrient distribution matters and, if so, to what degree. Given that the shift toward more carbohydrates has been associated with an overall increase in energy intake and an increase in obesity prevalence, dietary interventions to combat the obesity epidemic should focus on reducing total energy intake, perhaps by substituting protein intake in place of both carbohydrate and fat intake.

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