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ORIGINAL ARTICLE

Secular differences in the association between caloric intake, macronutrient intake, and physical activity with obesity

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Summary
Background: To determine whether the relationship between caloric intake, macronutrient intake, and physical activity with obesity has changed over time.
Methods: Dietary data from 36,377 U.S. adults from the National Health and Nutrition Survey (NHANES) between 1971 and 2008 was used. Physical activity frequency data was only available in 14,419 adults between 1988 and 2006. Generalised linear models were used to examine if the association between total caloric intake, percent dietary macronutrient intake and physical activity with body mass index (BMI) was different over time.
Results: Between 1971 and 2008, BMI, total caloric intake and carbohydrate intake increased 10—14%, and fat and protein intake decreased 5—9%. Between 1988 and 2006, frequency of leisure time physical activity increased 47—120%. However, for a given amount of caloric intake, macronutrient intake or leisure time physical activity, the predicted BMI was up to 2.3 kg/m^2 higher in 2006 that in 1988 in the mutually adjusted model ($P < 0.05$).

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Conclusions: Factors other than diet and physical activity may be contributing to the increase in BMI over time. Further research is necessary to identify these factors and to determine the mechanisms through which they affect body weight.

Introduction

During the past several decades the prevalence of obesity has dramatically increased in both developed and developing nations [1], including the United States where the prevalence has more than doubled between the 1970s and 2012 [2]. Obesity is primarily thought to occur as a result of energy imbalance, where energy intake exceeds energy expenditure over an extended period of time [3]. Both food energy supply and total energy intake have substantially increased in most Westernised countries [4,5], with evidence that the increase in energy supply closely matches the increase in overweight and obesity prevalence [5]. However, the association between energy intake and body mass index (BMI) is not consistent between studies [6,7], and recent evidence has challenged the notion that body weight is simply a function of ''calories in'' and ''calories out'' [8]. Furthermore, macronutrient composition may also be an important determinant of body weight independently of energy intake [9]. Epidemiological studies suggest that carbohydrate intake and protein intake are inversely associated with BMI, while fat intake is positively associated with BMI [9—12]. However, studies examining trends in macronutrient intake over time have shown inconsistent results [7,11], and it is not known if the association between macronutrient intake and BMI has been consistent over time.

Physical activity is commonly thought to be the other half of the energy balance equation. Although maintaining or increasing physical activity is associated with attenuated weight gain over time [13], recent reports suggest that self-reported leisure-time physical activity has significantly increased during the period when there have been dramatic increases in obesity [14,15]. Using a simplistic energy balance equation view, this would imply that the increases in physical activity over time have been overshadowed by greater secular increases in dietary intake. Given the complex relationship between energy intake, physical activity, and BMI, the objectives of this study were to (1) examine the secular trends in BMI, caloric intake, macronutrient intake, and physical activity over time in the United States population, and (2) to determine if caloric intake, macronutrient intake, and physical activity are independently associated with BMI and whether this association has changed over time.

Materials and methods

NHANES

The National Health and Nutrition Examination Survey is a series of nationally representative surveys of the United States non-institutionalised civilian population using a complex multi-stage probability sample design. A detailed explanation of the data collection methods for these surveys has been previously described elsewhere [16]. Data for this study was obtained from the NHANES I (1971—1975, $n = 31{,}973$), NHANES II (1976—1980, $n = 25{,}286$), NHANES III (1988—1994, $n = 33{,}994$), and NHANES continuous surveys (1999—2000, $n = 9965$; 2001—2002, $n = 11{,}039$; 2003—2004, $n = 10{,}122$; 2005—2006, $n = 10{,}348$; 2007—2008, $n = 10{,}149$). All participants in the NHANES gave their written informed consent prior to participation in the survey, and the methods used in the surveys were approved by the National Center for Health Statistics.

Study sample

All participants are interviewed by professionally trained staff in their own households. A subsample of these individuals also participates in a physical examination at a mobile examination centre, where 24-h dietary recall questionnaires are administered. Across all survey years, a total of 142,876 participants were interviewed, of which 124,062 participated in the physical examination. For the purpose of this analyses, participants were excluded if age was less than 20 or older than 74 years ($n = 59{,}809$), if BMI was less than 18.5 kg/m^2 or greater than 50 kg/m^2 or if data was missing for BMI ($n = 47{,}731$), if females were pregnant ($n = 1754$), or if participants reported exceedingly low ($\leq$1000 kcal/day) or high ($\geq$10,000 kcal/day) energy intakes or were missing data for energy intake (n = 31,667). This left a final sample size of 36,377 persons for this analysis. The analyses that examined secular trends in physical activity were additionally limited to NHANES III and NHANES continuous 1999—2006 due to data availability. The final sample size for the physical activity analysis was 14,419 persons.

Interview and examination measures

Questionnaires were used to assess age, sex, ethnicity (white or non-white), education (less than high school, high school or more than high school), and smoking status (never, past or current smoker). Height and weight were measured by trained technicians during the mobile examination. Standing height was measured in inches with a fixed stadiometer with a vertical backboard and a moveable headboard. Body weight was measured in pounds on a digital scale and converted to kilograms. Adults wore only underwear, disposable paper gowns, and foam slippers. BMI was computed as weight (kg) divided by height (m^2).

Dietary assessment

In all NHANES surveys, 24-h dietary recall questionnaires are administered to participants by trained interviewers who ask standardised probing questions in order to retrieve information on how food was prepared, and to allow for better recall of all foods consumed, including snacks, condiments, and beverages. In NHANES I (1971—1975) and NHANES II (1976—1980), in-person interviews were used to obtain self-reported dietary information via a 24-h dietary recall questionnaire that assessed food and beverage intake for weekdays only. In NHANES III (1988—1994), dietary information was obtained through a self-reported 24-h dietary recall using a computer-assisted, automated, interactive method for any day of the week. In NHANES 1999—2002, a multiple-pass computer-assisted dietary interview format was used to collect detailed self-reported information about all foods and beverages that were consumed the day prior to the in-person interview (weekday or weekend). In NHANES 2003—2008, 24-h self-reported dietary recalls were performed twice (3—10 days apart) using an automated multiple pass method. For all surveys, the data was used to estimate the total number of calories (kcal/day), fat (g), protein (g) and carbohydrates (g) from the foods and beverages consumed. Total amount of fat, protein and carbohydrates were converted to percent of total calories. The relative caloric intake was determined by converting total number of calories to kcal/kg of body weight.

Physical activity assessment

Self-reported physical activity was assessed using questionnaires. In NHANES I and NHANES II, the frequency of physical activity was not reported, and therefore these survey years were excluded from the physical activity and fully adjusted analyses. NHANES III assessed if participants engaged in physical activity in the past month, and if so, the frequency of their participation in select moderate and vigorous intensity activities (including walking, jogging, bicycling, swimming, aerobics or other forms of dancing, callisthenics, gardening or yard work, and weight lifting) during their leisure time. Individuals also had the option of listing up to four additional activities. In the NHANES continuous surveys, respondents provided additional information on the frequency of moderate and vigorous intensity activities, reported as times per day, week, or month. Participants were also asked: (i) about walking or biking as transportation to work, school or to run errands; (ii) if they had performed home or yard work that lasted at least 10 min and was at a moderate or vigorous effort, and (iii) if they had engaged in any moderate or vigorous leisure time activity. For the purpose of this analysis, physical activity from all surveys was converted to weekly bouts of physical activity. All activities were assigned a metabolic equivalent value (MET) [17], and only activities that were of at least moderate intensity (MET $\geq$3) were included in our definition of physical activity.

To determine the magnitude of difference between self-reported energy intake from NHANES over time, we compared self-reported energy intake to predicted daily caloric needs of each participant using the sex-specific Harris—Benedict equations [18], assuming a physical activity level of sedentary and moderately active (3—5 days/week) to obtain a reasonable upper and lower range for predicted daily energy needs.

Statistical analysis

Time was coded using the last year of each survey period (i.e. 1975, 1980, 1994, 2000, 2002, 2004, 2006, and 2008). Differences in BMI, caloric intake, macronutrient intake, and physical activity between 1971—1975 and 1988—1994 and all other survey years, were examined using by generalised linear models. The models were adjusted for age, ethnicity, education, and smoking status.

Trend analysis using general linear models was conducted to determine secular changes in the

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association between caloric intake, macronutrient intake and physical activity with BMI over time. Main effects of absolute caloric intake (kcals), relative caloric intake (kcal/kg), percent carbohydrate intake, percent fat intake, percent protein intake, physical activity frequency, and time, and the first order interactions with time on BMI were examined for males and females separately as sex-interactions were observed to be significant for 4 of the 6 outcomes. Each analysis contained two models. Model 1 examined the effect of each independent variable (calories, percentage calorie contribution from carbohydrates, fat, and protein, physical activity, and survey) on the dependent variable (BMI) while adjusting for age, ethnicity, education level, and smoking status. Model 2 was a fully adjusted model which further adjusted for caloric intake, physical activity, and either carbohydrate or fat intake where appropriate. To facilitate graphical representation, the 25th and 75th percentiles were used as points of comparison between surveys for total caloric intake, relative caloric intake, percent carbohydrate intake, percent fat intake, percent protein intake, and physical activity. Statistical significance was set at $P < 0.05$ and all analyses were conducted with SAS version 9.3. Data is reported as means $\pm$ SD unless otherwise indicated.

Results

Trends in BMI, caloric intake, macronutrient intake, and physical activity across time

Between 1971 and 2008, BMI increased 10% in men ($P < 0.001$) and 11% in women ($P < 0.001$) (Table 1). BMI was also significantly higher between 1988 and 2008 for both males and females ($P < 0.001$). There was a 10% higher total caloric intake across time for males, and a 14% high total caloric intake for females (Table 1) ($P < 0.001$). Compared to 1988—1994, total caloric intake continued to increase in males, while it remained relatively consistent in females (Table 1). In both sexes, relative caloric intake was similar between 1971 and 2008, but was moderately elevated in 1988—1994 ($P < 0.05$). Between 1971 and 2008, consumption of percent daily calories from carbohydrates increased 13% in males and 10% in females ($P < 0.001$). During this same time period, percent daily intake of fat and protein was 9% and 5% lower in males, respectively, and 8% and 7% lower in females, respectively ($P < 0.001$). Leisure time physical activity between 1988 and 2006 was 47% higher in males and 120% higher in females ($P < 0.001$) (Table 1).

Association between caloric intake, physical activity, and macronutrient intake over time on BMI

In males, there was no interaction between total caloric intake and time on BMI ($P = 0.20$), or significant association between total caloric intake and BMI ($P = 0.41$) in model 1. However, there was a significant positive main effect of time on BMI ($P < 0.001$) (Fig. 1A). After further adjustment for carbohydrate intake, fat intake and physical activity, there was a significant interaction between total caloric intake and time on BMI ($P = 0.04$), indicating that total caloric intake was not consistently related to BMI over time. The association between total caloric intake and time was non-significant ($P = 0.39$), although the positive association between time and BMI remained significant ($P < 0.001$) (Appendix 1A). In females, there was a significant interaction between total caloric intake and time on BMI ($P < 0.01$), and a significant positive association between time and BMI ($P < 0.001$). However, there was no association between total caloric intake and BMI ($P = 0.57$) (Fig. 1B). In the fully adjusted model, the interaction between calories and time on BMI became non-significant ($P = 0.09$), but the positive association between time and BMI remained ($P < 0.001$). There was a small negative association between total caloric intake and BMI ($P < 0.01$) (Appendix 1B).

In both males and females, there was a significant interaction between relative caloric intake and time on BMI ($P < 0.001$), indicating that there was a significant negative association between calories and BMI for each survey year that became stronger over time ($P < 0.001$). There was also a significant positive association between time and BMI, and a significant negative association between relative caloric intake and BMI for each survey year (Fig. 1C + D). Specifically, in the fully adjusted model, the difference in BMI between the 25th and 75th percentiles for relative caloric intake was 0.8 kg/m^2 and 0.7 kg/m^2 higher in 2005—2006 compared to 1988—1994 for males and females, respectively (Appendix 1 C + D).

In males, there was no significant interaction between physical activity and BMI for either model (Fig. 1E) ($P > 0.05$). In the fully adjusted model, there was no significant association between physical activity and BMI ($P > 0.05$), however, there was a significant positive association between time and BMI ($P < 0.001$). In females, there was a significant interaction between physical activity and time on BMI ($P < 0.001$) for both models, and a negative association between physical activity and BMI ($P < 0.001$) in 1988—1994 only (Fig. 2F). There was

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Table 1 Characteristics of males in NHANES 1971—2008, United States.

	NHANES I (1971—1975)	NHANES II (1976—1980)	NHANES III (1988—1994)	NHANES 1999—2000	NHANES 2001—2002	NHANES 2003—2004	NHANES 2005—2006	NHANES 2007—2008
Males								
n	1670	5181	3337	1768	1565	1677	1762	2125
Age (years)	50.1 ± 14.0	47.0 ± 17.1	43.3 ± 16.0	46.7 ± 15.6	45.7 ± 14.9	45.7 ± 15.8	45.2 ± 15.2	46.5 ± 15.0
Ethnicity (%white)	85.2	76.1*	68.7*	44.4*	50.3*	50.8*	48.2*	45.4*
Education (% ≥HS)	54.9	64.4*	61.0	62.2	72.7*	74.4*	73.6*	71.0*
Past smoker (%)	31.6	33.8	29.9	32.3	29.2	28.2	26.8	27.6
Current smoker (%)	42.0	38.4	33.1*	26.3*	28.5*	30.4*	29.6*	28.0*
BMI (kg/m^2)	25.9 ± 4.7	25.6 ± 4.8	26.9 ± 4.7*	28.0 ± 4.9*	28.1 ± 4.4*	28.2 ± 4.7*	28.7 ± 4.7*	28.6 ± 4.7*
Total calories (kcal)	2329 ± 1031	2378 ± 1021	2529 ± 1107*	2570 ± 1076*	2595 ± 1068*	2632 ± 1111*	2639 ± 1074*	2556 ± 1021*
PA (fq/wk)	NA	NA	6.0 ± 8.6	8.3 ± 9.6*	8.5 ± 8.7*	8.5 ± 9.5*	8.8 ± 8.8*	NA
Females								
n	1435	4523	3442	1432	1577	1470	1481	1932
Age (years)	49.5 ± 14.0	47.5 ± 17.1	43.0 ± 15.3*	46.7 ± 15.2	45.4 ± 14.9	46.7 ± 15.4	45.4 ± 15.0	47.0 ± 14.9
Ethnicity (%white)	85.6	74.8*	65.8*	40.6*	50.5*	50.1*	47.1*	43.8*
Education (% ≥HS)	57.8	66.5*	67.0*	65.7*	73.4*	75.7*	77.7*	73.3*
Past smoker (%)	12.6	15.6	17.4*	18.8*	19.4*	19.7*	18.8*	18.3*
Current smoker (%)	28.9	29.6	24.3	19.2*	21.3*	22.4*	20.7*	20.8*
BMI (kg/m^2)	26.3 ± 6.1	26.1 ± 6.4	28.3 ± 6.2*	28.9 ± 6.0*	28.9 ± 6.0*	29.2 ± 6.0*	29.4 ± 6.0*	29.5 ± 6.1*
Total calories (kcal)	1688 ± 670	1673 ± 548	1909 ± 734*	1930 ± 714*	1943 ± 674*	1986 ± 715*	1937 ± 693*	1930 ± 666*
PA (fq/wk)	NA	NA	4.1 ± 8.2	8.5 ± 8.6*	8.5 ± 8.5*	8.7 ± 9.2*	9.0 ± 7.7*	NA

Values are means ± SD unless otherwise noted. HS = high school, Kcal = kilocalorie; BMI = body mass index. * = significantly different from 1971 to 1975 ($P < 0.05$).
Note: NA = data not available for those survey years.

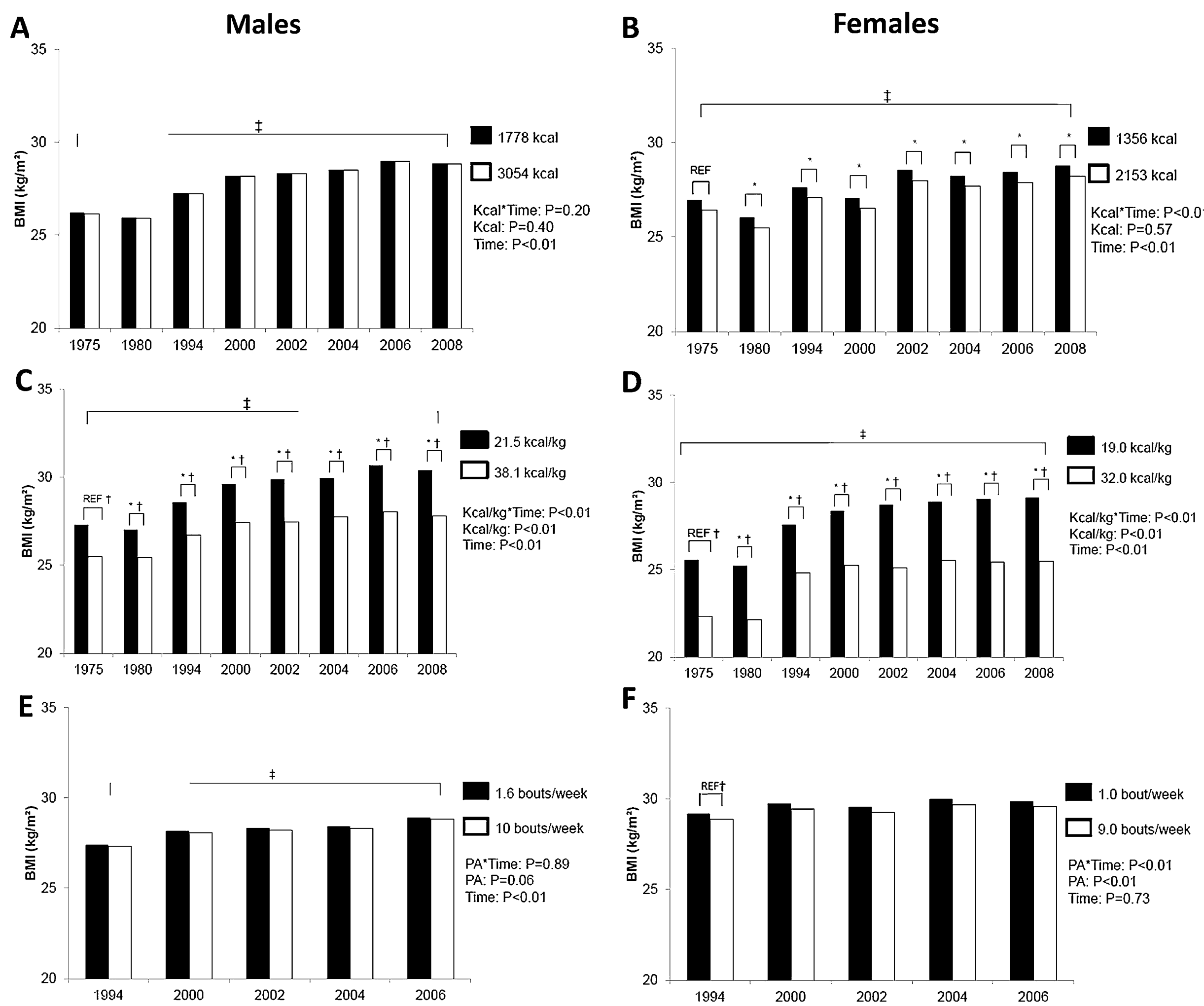

Figure 1 The association between total caloric intake, relative caloric intake and physical activity with BMI over time in males (A, C and E) and females (B, D and F). The model was adjusted for age, ethnicity, education, and smoking status. Black bars = 25th percentile; white bars = 75th percentile values for that variable. * = significantly different interaction with time compared to the referent survey (1988—1994) ($P < 0.05$). † = significant main effect of total caloric intake, relative caloric intake, or physical activity ($P < 0.05$) within that survey year ($P < 0.05$). ‡ = significant main effect of time ($P < 0.05$). BMI = body mass index, REF = referent year.

no association between time and BMI for either model ($P > 0.05$).

In model 1 and model 2 for both males and females (Fig. 2A + B), there was no interaction between percent dietary carbohydrate intake and time on BMI ($P > 0.05$), but there was a significant positive main effect of time ($P < 0.05$). In the fully adjusted model, there was a significant negative association between carbohydrate intake and BMI in males ($P < 0.001$), but not females ($P = 0.30$) (Appendix 2A + B).

For both males and females, there was a significant interaction between fat intake and time on BMI in model 1 ($P < 0.001$). There was a significant positive main effect of time and a positive association between fat intake and BMI that grew stronger over time (Fig. 2C + D). After adjustment for caloric intake, carbohydrate intake, and physical activity, the interaction between fat intake and time became non-significant ($P > 0.05$), but the positive effects of time and fat intake on BMI remained (Appendix 2C + D) ($P < 0.001$).

For both males and females, there was no interaction between protein intake and time on BMI for either model ($P > 0.05$) (Fig. 2E + F). In model 1, there was a positive main effect of time and protein intake on BMI ($P < 0.001$). After adjustment for caloric intake, carbohydrate intake, and

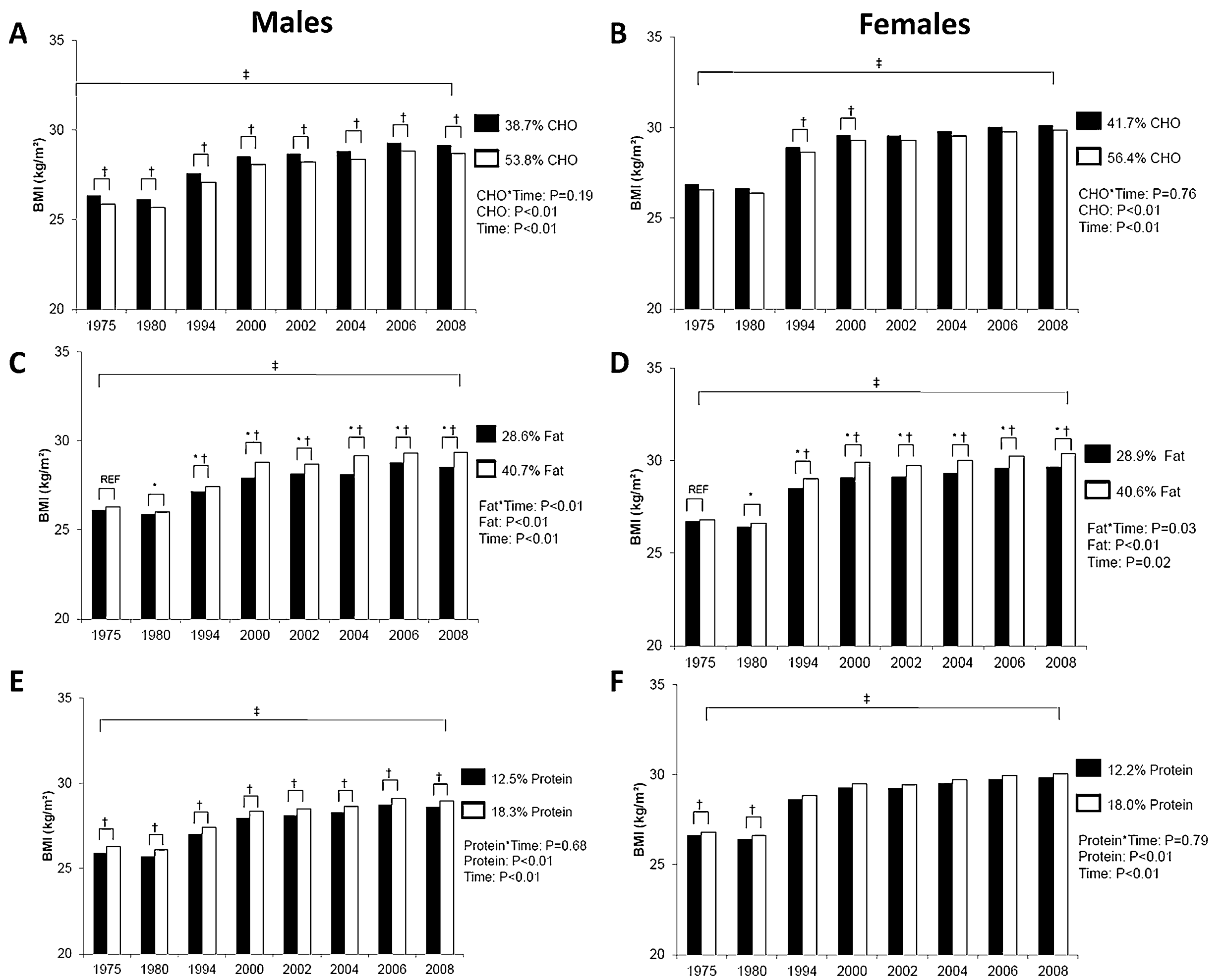

Figure 2 The association between percent carbohydrate intake, percent protein intake and percent fat intake with BMI over time in males (A, C and E) and females (B, D and F). The model was adjusted for age, ethnicity, education, and smoking status. Black bars = 25th percentile; white bars = 75th percentile values for that variable. * = significantly different interaction with time compared to the referent survey (1988—1994) ($P < 0.05$). † = significant main effect of carbohydrate, fat, or protein intake ($P < 0.05$) within that survey year ($P < 0.05$). ‡ = significant main effect of time ($P < 0.05$). BMI = body mass index, REF = referent year.

physical activity, the positive effect of time remained, and the association between protein intake and BMI became negative (Appendix 2E + F) ($P < 0.05$).

Differences between self-reported energy intakes in NHANES versus predicted energy requirements

When energy requirements were predicted assuming a sedentary activity level, males over reported energy intake by 22%-26%, while females under reported energy intake for NHANES I and NHANES II by only 1—3%, and over reported energy intake by 5—8% for the subsequent survey years. Conversely, when energy requirements were predicted assuming a moderately active lifestyle, which is what most participants reported, males under reported energy intake by only 2—6%, whereas females under reported energy intake by 16—24%, with the greatest degree of under reporting occurring in NHANES I and NHANES II.

Discussion

Despite an overall increase in caloric intake in the United States over the past four decades when concurrent increases in obesity were observed, we were unable to demonstrate a direct relationship between caloric intake and increase in BMI over time. This is in line with recent suggestions that other factors beyond total caloric intake may be contributing to the epidemic rise in obesity.

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When caloric intake was expressed as a function of body weight, there remained a clear inverse association between caloric intake and BMI. This finding is in line with those of several other studies in which individuals with obesity reported consuming similar or fewer daily calories than those who are normal weight [7,11]. While this has frequently been attributed to underreporting [19,20], several additional possible explanations must be considered. First, approximately half of the U.S. adult population has been reported to be attempting weight loss [21], and therefore overweight and obese individuals may have been more likely to be restricting caloric intake. Second, individuals with a high BMI may be more likely to have a lower resting metabolic rate due to a history of weight cycling [22], restricting caloric intake [23], or due to a decrease in the thermic effect of food [24], although this finding is not consistent between studies [25]. This decreased energy need may be particularly more apparent when caloric intake is expressed relative to body weight as adipose tissue requires less energy to maintain than lean mass. Third, there is emerging evidence that hormonal changes resulting from intrinsic (e.g. stress, lack of sleep) or extrinsic (e.g. environmental toxins) may alter the disposition of calories within the organism [26]. For example, recent studies have observed that persistent organic pollutants, chemicals that can be found in food and everyday products, are associated with higher BMI and waist circumference and may be partially attributable to the rise in obesity rates [27]. As well, the majority of agricultural beef cattle are given exogenous sex steroids in order to increase weight gain and feeding efficiency. Although there are concerns that this may influence human health, more research in this area is needed [28]. Additional novel factors that may be contributing to the obesity epidemic include increases in pharmaceutical prescriptions associated with weight gain, higher maternal age, reduction in variability of ambient temperature, decreased prevalence of smoking, inadequate amount of sleep and low calcium [29—32]. Finally, studies on the intestinal bacteriome are revealing significant variations in gut microbiota between obese and non-obese animals and humans. These variations may cause a greater amount of caloric extraction from indigested dietary substances, which may increase body weight even when caloric intake does not increase [33]. Although we observed an inverse association between caloric intake and BMI in the present study, BMI was still 2.3 kg/m^2 higher in 2005—2006 than in 1988—1994 for a given caloric intake even after adjustment for macronutrient intake, or physical activity. Thus, our novel observation of increased BMI for a given caloric intake is in line with the emerging notion that additional factors may have significantly altered how energy intake relates with BMI over time.

Whether self-reported dietary intake accurately reflects an individual's true dietary intake has been questioned [34]. Indeed, doubly-labelled water studies typically show that individuals underreport their energy intake, and that the magnitude of the underreporting may be larger in people who are obese [35]. National self-reported dietary survey data, such as the NHANES, is the primary source of information on the U.S. populations food and beverage consumption, and is used to assess dietary trends [11], adherence to dietary recommendations and to inform public policy [36]. Notwithstanding the known errors of dietary assessment, it is interesting that we observe consistent trends over time in terms of how dietary intake relates with obesity and how this relationship has changed over time. This lends more confidence to our primary findings and suggests that there are either physiological changes in how diet relates with body weight or differences in how individuals are reporting their dietary intake over time. The assessment of changes in energy intake is difficult as over time there have been some changes in dietary intake methodology and food consumption databases [36]. Over the years food databases were continually updated to include new and ethnic-specific foods, and 24-h dietary recalls are now available for any day of the week. These improved dietary assessment methods should be able to capture more of foods individuals are actually consuming over time. While it has been suggested that self-report bias in dietary intake may have increased over time [34], our results indicate that self-report bias has remained relatively consistent or has slightly improved over time. However, females may be more likely to under report energy intake than males. A potential explanation for this is that females may have a greater degree of social desirability for low body weights and social approval bias compared to males [37,38].

Over the past several decades low carbohydrate, high-protein diets have increased in popularity as they have been suggested to be effective for weight loss [39]. In contrast, the present study observed an inverse association between BMI and carbohydrate and protein intake, and a positive association between fat intake and BMI, which is consistent with other studies [10,12]. However, our results indicate that for a given macronutrient intake, BMI was higher over time. It is unclear if these findings are confounded by the increased likelihood of obese individuals to engage in low carbohydrate diets. Furthermore, evidence from weight loss trials suggests that total energy intake contributes more to body weight than macronutrient composition of the diet [40].

A lack of physical activity has been suggested by some to be a major determinant of the rise in the obesity epidemic [41]. Indeed, normal weight adults are reported to engage in more moderate and vigorous physical activity compared to overweight and obese U.S. adults [42]. However, this study and others [14,15] suggest that the frequency of self-reported leisure time physical activity is higher across the same time period that BMI has been seen to increase. It is important to highlight that all physical activity measures were self-reported, and may be over reported when compared with objectively measured physical activity from accelerometers [43]. Unfortunately, as objectively measured physical activity is only currently available for NHANES 2003—2006, we cannot determine secular changes in self-report bias in physical activity over time, or the association between objectively measured physical activity and BMI over time. However, for most survey years there was not an association between physical activity and BMI, which is consistent with evidence from intervention research that suggests that physical activity may contribute much less to changes in body weight than energy intake [44]. Furthermore, as with the other factors, we observed that the BMI associated with a given leisure time physical activity frequency was still higher over time in men. This may be attributed to changes in non-leisure time physical activity such as reductions in occupational physical activity [14] or increasing screen time [45]. However, a study using doubly labelled water demonstrated that there is no difference in total energy expenditure between traditional hunter-gathers, subsistence farmers and modern Westerners [46]. Thus, numerous other factors in addition to energy intake and physical activity may be important to consider when trying to explain the rise in obesity, and should be further evaluated in future studies.

A major strength of this study was the use of United States national survey data. We were able to capture secular trends in BMI, energy intake, macronutrient intake, and physical activity over a considerable amount of time. One of the limitations of this study is that NHANES is a cross-sectional survey and therefore causality cannot be implied. This study is also limited by the use of self-reported dietary and physical activity data, which may result in under or over reporting of these measures [47]. As well, the 24 h food recall questionnaire may not accurately reflect an individual's typical diet, and the degree to which the frequency of physical activity reflects total physical activity or energy expenditure is unclear. We were also unable to consider the influences of any of the previously mentioned factors that have been shown to influence body weight (e.g. sleep, certain types of medication, differing ratios of gut microbiota, etc.). Finally, due to the nature of the analyses, we were unable to weight the analyses to be representative of the U.S. population. However, the results are still internally valid and are based on a large sample of U.S. men and women over a long time span.

In conclusion, BMI, energy intake, carbohydrate intake, and leisure-time physical activity have all significantly increased over the last four decades in the United States, while fat and protein intake have decreased. However, for a given level of energy intake, macronutrient intake, and physical activity, BMI was higher over time. These results may be a function of other factors significantly modifying how energy intake and expenditure influence body weight over time, or they may be due to biases in reporting of diet and physical activity over time. However, given the consistency of these results and the increasing evidence that multiple factors beyond diet and physical activity are associated with increases in body weight, further investigation of how these novel factors influence body weight independent of lifestyle factors is warranted.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

JLK designed the study, REB, PM and PM performed the statistical analyses, REB drafted the manuscript, AMS and CIA provided critical revisions to the writing of the manuscript and offered guidance for statistical analysis. All authors read and approved the final manuscript.

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Appendix 1.

See Fig. A1.

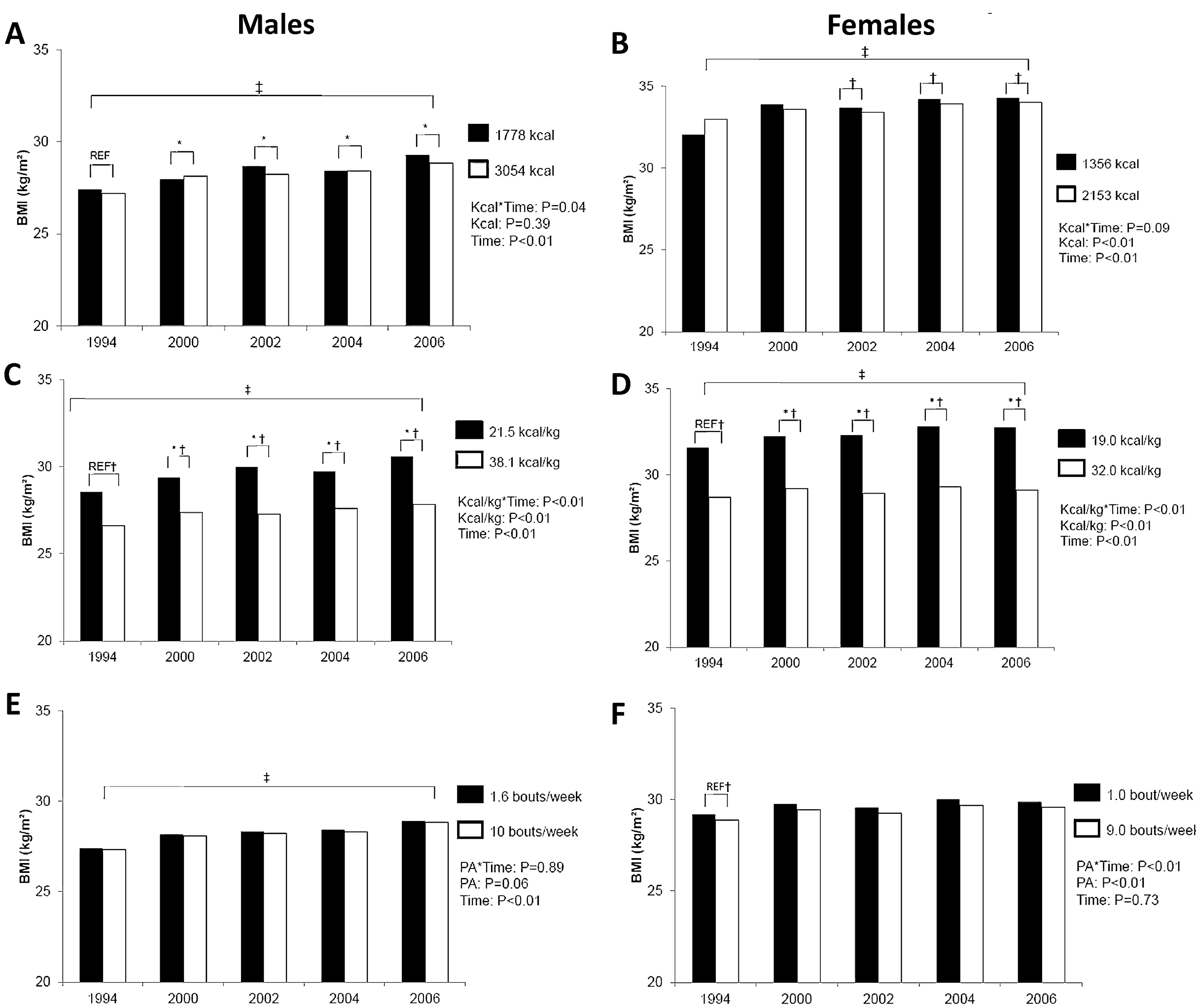

Figure A1 The association between total caloric intake, relative caloric intake and physical activity with BMI over time in males (A, C and E) and females (B, D and F). The model was adjusted for age, ethnicity, and education, in addition to carbohydrate intake, fat intake, and physical activity (A + B), and carbohydrate intake, fat intake, and relative caloric intake (C). Black bars = 25th percentile; white bars = 75th percentile values for that variable. * = significantly different interaction with time compared to the referent survey (1971—1975) ($P < 0.05$). † = significant main effect of total caloric intake, relative caloric intake, or physical activity ($P < 0.05$) within that survey year ($P < 0.05$). ‡ = significant main effect of time ($P < 0.05$). BMI = body mass index, REF = referent year.

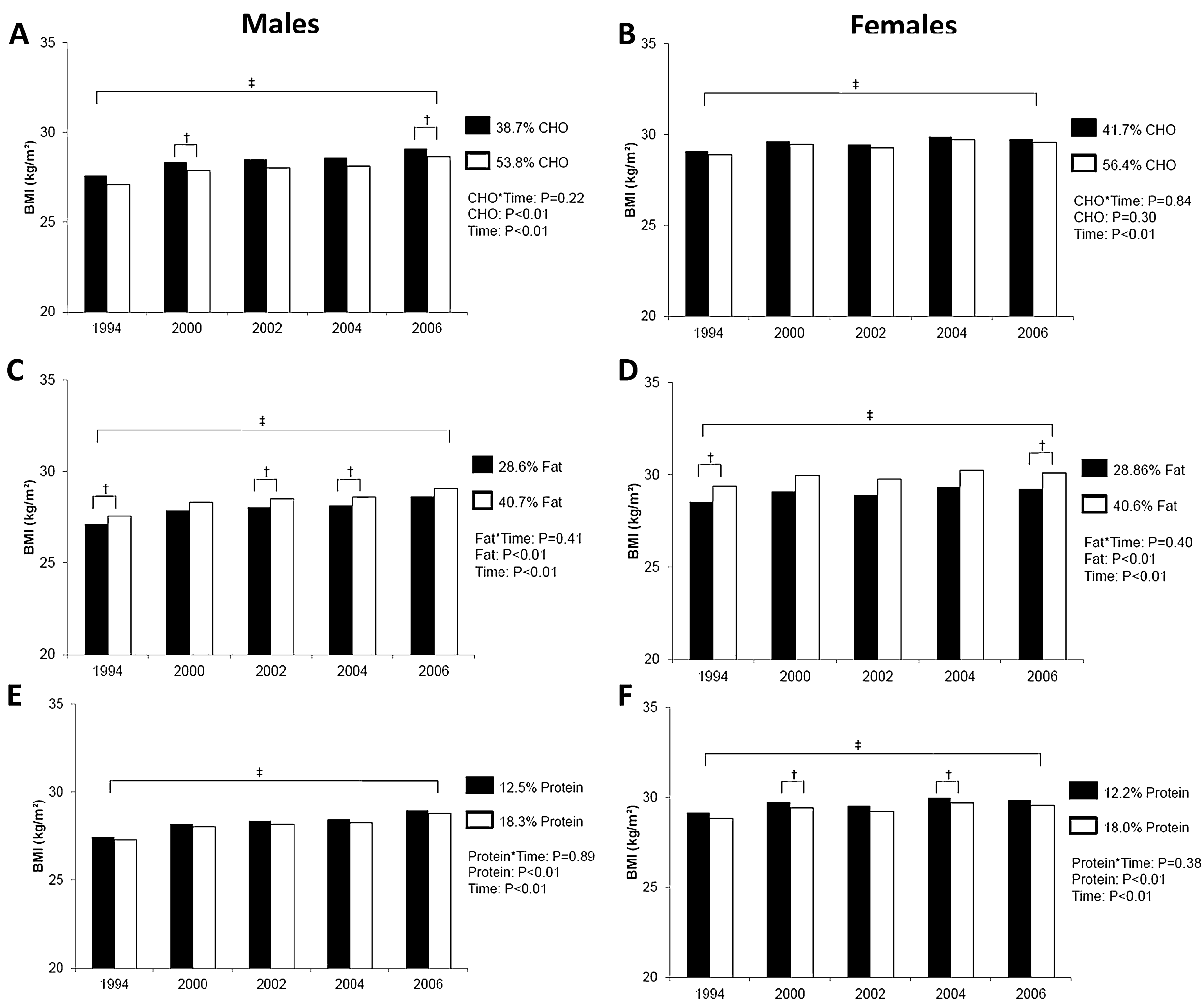

Figure A2 The association between percent carbohydrate intake, percent protein intake and percent fat intake with BMI over time in males (A, C and E) and females (B, D and F). The model was adjusted for age, ethnicity, education, and smoking status, in addition to relative caloric intake, physical activity, and carbohydrate or fat intake (A + B), and relative caloric intake, physical activity, and carbohydrate intake (C). Black bars = 25th percentile; white bars = 75th percentile values for that variable. * = significantly different interaction with time compared to the referent survey (1971—1975) ($P < 0.05$). † = significant main effect of carbohydrate, fat, or protein intake ($P < 0.05$) within that survey year ($P < 0.05$). ‡ = significant main effect of time ($P < 0.05$). BMI = body mass index, REF = referent year.

Appendix 2.

See Fig. A2.

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