

**SECULAR TRENDS IN THE RELATIONSHIP BETWEEN CALORIC INTAKE,  
CARBOHYDRATE INTAKE, AND PHYSICAL ACTIVITY WITH OBESITY**

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## ABSTRACT

The prevalence of obesity has increased dramatically over the past several decades. A number of factors contributing to obesity are well established; however, the etiology of obesity remains unclear. We set out to examine how caloric intake, carbohydrate intake, and physical activity associate with obesity, and whether this association has changed over time using data from the National Health and Nutrition Survey (NHANES). Linear regression was conducted to determine secular changes in the association between physical activity, caloric intake, and carbohydrate intake with BMI. The interaction of relative caloric intake (kcal/kg) and time on BMI was significant after adjusting for physical activity and carbohydrate intake, as the difference between the predicted BMI for any two relative caloric intakes increased over time ( $P < 0.0001$ ). The main effects of time on BMI was significant, indicating that a given relative caloric intake predicted a greater BMI over time ( $P < 0.0001$ ). The association between carbohydrate intake and time revealed significant main effects of time, as a given carbohydrate intake predicted a greater BMI over time ( $P < 0.05$ ). The interaction between exercise frequency (times/week) and time on BMI was significant for females; the difference between the predicted BMI for two physical activity levels increased over time ( $P = 0.0006$ ). The main effects of time on BMI was significant for both sexes, indicating that a given physical activity level predicted a greater BMI over time ( $P < 0.0001$ ). Our results indicate that neither caloric intake nor physical activity consistently predicted BMI over time. We speculate that additional factors may be influencing how physical activity and dietary factors relate with obesity.

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## LIST OF ABBREVIATIONS

BMI	body mass index
CVD	cardiovascular disease
LTPA	leisure-time physical activity
MET	metabolic equivalence of task
NHANES	National Health and Nutrition Examination Survey

## INTRODUCTION

Despite advancements in medicine and technology in the 21st century, North America is plagued by an obesity epidemic (1). In fact, the prevalence of obesity has increased drastically over the previous several decades (2). Data from the National Health and Nutrition Examination Survey (NHANES) suggests that obesity has more than doubled in adults from 15.8% in 1971 to 37.6% in 2008 (3). Similarly, in Canada, the prevalence of overweight and obesity have increased from approximately 27% and 6% in 1985 to approximately 35% and 16% in 2003, respectively (4). Reports indicate that more than half of the US and Canadian adult population is currently overweight or obese (4, 5). This is of concern as obesity is strongly associated with several chronic diseases including cardiovascular complications and type II diabetes (6).

A number of factors contributing to the development of obesity are well established; however, the etiology of obesity is still unclear. According to the law of thermodynamics, weight gain resulting in obesity is attributed to a sustained positive energy balance, which occurs when energy intake chronically exceeds energy expenditure. This dis-equilibrium in energy balance has been widely studied in experimental studies (7). However, the relative contribution of increased energy intake and decreased energy expenditure remains unclear and other important factors also appear to contribute to excessive adiposity. Currently, diet composition is also considered a probable factor that may be associated with the development of obesity (8). Several studies have found an inverse relationship between body fat and carbohydrate intake but have not simultaneously considered energy intake and physical activity (9,10,11,12). Epidemiological studies suggest that differences in the amount of physical activity may contribute to differences in body weight and consequently play an important role in the

development of obesity (13,14,15). The available research examining the secular trends of leisure-time physical activity indicates a general increase over time (16,17,18,19).

Epidemiological studies examining energy intake are less conclusive with reports indicating both, a positive (20), and inverse (23, 24,25) relationship between energy intake and BMI.

Moreover, research examining the secular trends of energy intake is inconclusive as to whether the increased prevalence of obesity has been mirrored by an increase in energy intake.

Moreover, other factors including macronutrient intake, particularly carbohydrate intake, have been positively associated with BMI (9,10,11,12). Research examining secular trends indicates that the percentage of calories derived from carbohydrates has increased (24,25).

While some studies have examined physical activity (16,17,18,19), caloric intake (15,26,27,28), and carbohydrate intake (24,25,29) trends over time, they have not directly examined how these factors are independently associated with obesity, and whether this association has changed over time. Given that overweight and obesity rates are rising at an alarming rate, the present study will attempt to better understand the relationship between caloric intake, carbohydrate intake, and physical activity, with BMI.

## REVIEW OF THE LITERATURE

### *Obesity*

The prevalence of obesity in the United States has been increasing for at least 100 years, with an apparent acceleration in the past 3 decades (30). Obesity rates have been similarly increasing in Canada (31), specifically, the prevalence of overweight and obesity have increased from approximately 27% and 6% in 1985 to approximately 35% and 16% in 2003, respectively (4). Obesity is associated with many diseases including cardiovascular disease (CVD), type II diabetes, hypertension, dyslipidemia, functional disability, various types of cancer, and premature death (32). In the present study we will examine the association of obesity with its two main culprits: physical activity and diet, and how this relationship has changed over time.

### *Physical Activity and Obesity*

Increasing physical activity has become an important part in public health strategies to prevent weight gain. There is evidence to suggest that differences in the amount of physical activity may contribute to differences in body weight and consequently play an important role in the development of obesity (14). Cross-sectional and population studies show a negative relationship between physical activity levels and BMI (15,16). Moreover, longitudinal cohort studies show that high levels of physical activity are protective against obesity (33,34). However, this association has not been demonstrated in all studies, suggesting that other factors may be responsible for the development of obesity (35).

While studies on secular trends in energy expenditure from physical activity are sparse, the available literature indicates that there has been an increase in leisure-time physical activity

(LTPA) over time (16,17,18,19). A study by Craig et al (2004) reports that LTPA increased from 1981 to 2000 in Canadian men and women of all ages, educations, and income groups (16). Moreover, a study by Talbot et al (2003) indicates that LTPA increased from 30 to 80 MET min/day from the 1960s to the 1990s for men (17). Similarly, a study by Jacobs et al (1991) suggests that leisure-time activity has consistently increased from 1957 to 1975 in men, and from 1980 to 1987 in women (18). Additionally, a population-based surveillance study examining 20-year trends in physical activity, suggests that energy expenditure from lifestyle physical activity and leisure-time physical activity has increased between 1980 and 2000 for both genders (19). Therefore, the available research examining the secular trends of energy expenditure is indicative of a general increase over time.

### *Caloric Intake and Obesity*

When examining dietary factors, both positive (20) and inverse relationships between body fatness and energy intake (21,22,23) have been reported. Moreover, research on trends in energy intake over time is mixed as to whether there has been a shift in energy intake. Some studies suggest that energy intake has increased over the last several decades (26,27); whereas others suggest that little or no change in energy intake has occurred (28). On the contrary, some studies suggest that energy intake has actually decreased over the last few decades (15). Studies based on population surveys (27,35) and aggregate level data (26) on dietary intake in the US population show a clear trend toward increased dietary energy intake. A study by Nielsen et al (2002) using nationally representative data demonstrate that total daily energy intake increased from 1791 to 1985 kcal between in 1977 and 1996, equating to an 11% (200 kcal/year) increase (27). Moreover, data from the USDA Nationwide Food Consumption Survey, indicates that

average daily energy intake increased from 2450 to 2618 kcal in men, and 1542 to 1877 kcal in women between 1971 and 2000 (36). Data on food supply in the US also indicate that the per capita per day availability of food energy has increased 15.2% from 1970 to 1994 (26). Therefore, consistent with the trends in overweight and obesity, several studies in the literature are supportive of a general increase in energy intake over time.

On the contrary, data from the National Health and Nutrition Examination Survey (NHANES), a large survey representative of the US population, indicates that energy intake has been declining (15). A study by Heini et al (1997) examined secular trends in dietary intake using NHANES and found that total energy intake has modestly decreased in both sexes, by 3% in women and by 6% in men, between 1976-1980 (NHANES II) and 1988-1994 (NHANES III), and has remained relatively stable from 1999-2008 (28). Therefore, the literature examining the secular trends in caloric intake is inconsistent.

The discrepancies in the literature pertaining to the relationship between obesity and caloric intake and their secular trends suggest that energy intake should be evaluated in relation to physical activity. Few studies have concurrently examined the relative contribution of energy intake and physical activity on body weight. When adjusting for caloric intake, some studies have found that physical activity is inversely related to increases in BMI (37,38), while others have failed to show such associations (39). It has therefore been difficult to determine the relative importance of these behaviours to weight change.

### *Diet Composition and Obesity*

Although much research is targeted at caloric intake and energy expenditure, other important factors also appear to lead to increased adiposity (40). The energy content of food is

mainly derived from carbohydrate, fat, and protein, and there has been a consistent emphasis over the past four decades to reduce the proportion of energy from fat to reduce CVD risk (41). However, the consequences of decreasing the proportion of fat in the diet on obesity are controversial (42). Weight loss studies have failed to show that restricted-energy high-fat diets have a different effect from low fat diets on energy expenditure or body composition changes (43,44). Similarly, Roust et al (45) report no significant changes in energy expenditure or body composition after participants switched from a high-fat to a low-fat diet.

However, several correlational studies show that macronutrient intake, particularly carbohydrate intake, is inversely related to body fatness (9,10,11,12). Conversely, other studies show that carbohydrates promote obesity (independent of energy intake)(40); this may result from the postprandial insulin response to carbohydrate consumption, which may reduce fat oxidation and increase fat synthesis and storage (40). This implies that dietary composition, in addition to energy content, may influence the development of obesity, and for this reason we decided to focus on carbohydrate consumption as opposed to the usual target, fat consumption.

While weight-loss interventions have largely centered on the reduction of dietary fat as a means of combating obesity (46), the general consensus in the literature is that there has been an increase in the percentage of dietary calories derived from carbohydrate. A review of the literature by Briefel et al. (2004) suggests that the relative proportion of calories from fat decreased, protein intake remained stable, whereas carbohydrate increased between 1971-1974 and 1999-2000 (24,25). US national dietary surveys suggest that the percentage of energy from carbohydrate has increased uniformly across both sexes and across normal weight, overweight, and obese groups from the early 1970s to 2006, while the percentage of energy from fat and

protein decreased (29). Specifically, in NHANES I (1971-1975), the percentage of energy from carbohydrates was 45.4% for women. By NHANES 2005–2006, this figure increased to 49.63%. In NHANES I (1971-1975), the percentage of energy from carbohydrates was 42.2% for men. By NHANES 2005–2006, this figure increased to 47.7% (29). Moreover, food supply data indicate that the greatest increase in per capita availability of macronutrients occurred for carbohydrates (27.2%) from 1970 to 1994 (26). Thus, a large body of evidence across different sources of data are indicative of an increase in carbohydrate consumption over time.

### *Additional Contributing Factors to Obesity Epidemic*

The scientific literature has largely focused on reduced physical activity, increased caloric intake, and dietary composition as postulated causes for the obesity epidemic. Here we will discuss several additional factors for which the evidence is also circumstantial, yet equally compelling.

According to cross-sectional studies and incident obesity in longitudinal studies, hours of sleep per night has been shown to be inversely related to BMI and obesity in adults (47). Sleep restriction in humans has been shown to increase hunger and appetite (48). Given the clear reductions in average sleep from over 9 hours to just over 7 hours per night over the past several decades among US adults (49,50), it is plausible that sleep may in part be contributing to the rise in obesity. Another plausible contributor to the obesity epidemic is the endocrine disruptors present in the food chain (51), most of which are antiandrogens and may alter nutrient partitioning towards a more fatty body composition (52). Endocrine disruptors are industrially produced substances that can disturb normal hormonal regulation and may lead to increased adiposity. Moreover, certain pharmaceutical drugs including antipsychotics, antidiabetics,

antihypertensives, and anticonvulsants have all been linked to weight gain as these drugs are active at many receptors that are involved in body weight regulation (53). These pharmaceutical drugs were introduced or had their use dramatically increase in the past three decades (54). Specifically, antidiabetic, antihypertensive, and anticonvulsant prescriptions have increased nearly twofold from 1990 to 2001 (55,56). A fourth factor may be the secular decline in smoking rates (57). Nicotine has been known to have both thermogenic and appetite-suppressant effects (58), and epidemiological and clinical studies consistently show that weight gain follows smoking cessation (59). It is estimated that smoking cessation may be responsible for as much as one-quarter of the increase in the prevalence of overweight in men and for about one-sixth of the increase in women between 1978 and 1990 (59).

The evidence for these additional factors is compelling, making their contribution to the obesity epidemic a definite possibility. However, research addressing these factors is not available, and may be why there is a discrepancy in the literature for the association of diet and physical activity with obesity. The aim of this thesis is to better understand changes in the relationship between caloric intake, carbohydrate intake, and physical activity with BMI over time.

While the evidence for these additional factors in the secular increase in overweight and obesity is compelling, no systematic investigation of these factors has been thus far undertaken, as research addressing these factors is not available. We set out to see if research directed at such additional factors is warranted and to examine whether they are one of the reasons as to why there is a discrepancy in the literature for the association of diet and physical activity with

obesity. Specifically, the aim of this thesis is to better understand changes in the relationship between caloric intake, carbohydrate intake, and physical activity with BMI over time.

**MANUSCRIPT**

Secular trends in the relationship between caloric intake, carbohydrate intake, and  
physical activity with obesity

## **ABSTRACT**

**Aim:** To better understand changes in the relationship between caloric intake, carbohydrate intake, and physical activity with BMI over time.

**Methods:** A sample of the US population was examined using data from NHANES. Linear regression was conducted to determine secular changes in the association between physical activity, caloric intake, and carbohydrate intake with BMI over time.

**Results:** The interaction of relative caloric intake (kcal/kg) and time on BMI was significant for both sexes after adjusting for physical activity and carbohydrate intake, as the difference between the predicted BMI for any two caloric intakes increased over time ( $P < 0.0001$ ). The main effects of time on BMI was significant, indicating that a given caloric intake predicted a greater BMI over time ( $P < 0.0001$ ). The association between carbohydrate intake (% of total calories) and time revealed significant main effects of time, as a given carbohydrate intake predicted a greater BMI over time ( $P < 0.05$ ). The interaction between exercise frequency (times/week) and time on BMI was significant for females after adjusting for caloric and carbohydrate intake, as the difference between the predicted BMI for two physical activity levels increased over time ( $P = 0.0006$ ). The main effects of time on BMI was significant for both sexes, indicating that a given physical activity level predicted a greater BMI over time ( $P < 0.0001$ ).

**Conclusions:** Our results indicate that neither caloric intake nor physical activity consistently predicted BMI over our study time span. We speculate that additional factors may be influencing how physical activity and dietary factors relate with obesity.

## **Introduction**

Reports indicate that the prevalence of obesity has increased dramatically over the past several decades (2). Data from the National Health and Nutrition Examination Survey (NHANES) indicate that obesity has more than doubled from 1971 to 2008 (3). The association between excess body weight and risk of deleterious health outcomes, including cardiovascular complications and diabetes, has been clearly established (5). Projections indicate that if unabated, by 2030 the prevalence of overweight and obesity in the U.S. will reach 86% and 51% of the population, respectively (60).

Although the etiology of obesity remains unclear, a number of lifestyle-related factors contributing to obesity have fostered the most attention. Weight gain resulting in obesity is most commonly attributed to a sustained positive energy balance, which occurs when energy intake chronically exceeds energy expenditure (7). The weighted evidence suggests that there has been a secular increase in energy expenditure and physical activity (16,17,18,19). However, the literature examining dietary intake is less clear with some reports suggesting that energy intake has increased (26,27), whereas others suggest that little or no change in energy intake has occurred (28). On the contrary, some studies suggest that energy intake has actually decreased over the last few decades (15). Diet composition is also considered a probable factor that may be associated with the development of obesity as numerous studies report an inverse relationship between body fat and carbohydrate intake (9,10,11,12). However, opposite to what we would expect, research examining secular trends indicates that the percentage of calories derived from carbohydrates has increased (24,25).

Given the need for public health interventions that target factors contributing to the rising rates of overweight and obese, the present study will attempt to better understand the relationship between caloric intake, carbohydrate intake, physical activity, and BMI. Studies have not directly examined whether the independent association of these factors with obesity has changed over time.

Thus, the objectives of the following analysis were: 1) to examine the secular trends in BMI, caloric intake, physical activity, and carbohydrate intake, and 2) to investigate how caloric intake, physical activity, and carbohydrate intake are independently associated with BMI and whether this association has changed over time.

We hypothesize that over time, caloric intake, carbohydrate intake, and physical activity levels have increased in concert with the prevalence of overweight and obesity. Moreover, we predict a positive association between caloric intake with BMI and a negative association between carbohydrate intake and physical activity with BMI.

## **Methods**

### *National Health and Nutrition Examination Survey*

The National Health and Nutrition Examination Survey (NHANES) is a series of nationally representative surveys by the National Center for Health Statistics (Centers for Disease Control and Prevention), focusing on varying health issues to produce national health statistics. It began in 1960 and continues today. Each cross sectional survey provides a national estimate for the US population at the time of the survey, enabling examination of trends over time in the population. The eight NHANES datasets used in the analysis are described below:

### *NHANES I (1971-1975)*

The first National Health and Nutrition Examination Survey was conducted on a nationwide probability sample of 32 973 individuals, 1-74 years of age, from the civilian, noninstitutionalized population of the United States. The sample was selected so that certain population groups thought to be at high risk of malnutrition (individuals with low income, preschool children, women of childbearing age, and the elderly) were oversampled at preset rates (61). Adjusted sampling weights were computed within 60 age-sex-race categories in order to inflate the sample to closely reflect the U.S. civilian noninstitutionalized population between 1-74 years of age. Information for all examined persons in NHANES was obtained by means of a household interview, a 24-hour dietary intake recall interview, a food frequency interview, a general medical examination, and anthropometric measurements (62).

### *NHANES II (1976-1980)*

The second National Health and Nutrition Examination Survey is a nationwide probability sample of 27 801 persons from 6 months to 74 years of age, from the civilian noninstitutionalized population of the United States. The sample was selected so that certain population groups assumed to be at special risk of having nutritional problems (persons with low incomes, preschool children and the elderly) were oversampled at preset rates. Adjusted sampling weights were computed within 76 age-sex income groups in order to inflate the sample to closely reflect the target population at midpoint of survey (63). Data collection in NHANES II followed the same procedure to that as NHANES I (64).

### *NHANES III (1988-1994)*

The third National Health and Nutrition Examination Survey was comprised of two phases, each using a complex, multistage, probability sampling method to select a sample of 33 994 persons representative of the total non-institutionalized civilian population in the United States. In 1992, data collection was conducted by personal interview using Computer-Assisted Personal Interview (CAPI) technology. Oversampling was conducted among African Americans and Hispanic Americans (to account for largest minorities in the U.S., as well as among children and the elderly (65).

Information for all examined sample persons in NHANES was obtained using a household questionnaire assessing demographic items and a general medical history questionnaire. A 24-hour dietary intake recall interview and a food frequency interview were administered by trained dietary interviewers at the mobile examination center. Anthropometric measurements and general medical examination were carried out by physicians also at the mobile examination center (66).

*NHANES (1999-2000), (2001-2002), (2003-2004), (2005-2006), (2007-2008)*

Beginning in 1999, NHANES became a continuous survey that released data on a biannual basis. An annual sample of individuals ranging from 2 months to over 80 years of age, representative of the non-institutionalized, civilian United States population was selected using a stratified multi-stage probability sample design. Oversampling was conducted among African Americans, Hispanic Americans, and individuals greater than 60 years of age (67). Data was collected continuously by personal interview using Computer-Assisted Personal Interview (CAPI) technology and by physical examination by a health team consisting of physicians and dietary/health interviewers in specialized mobile examination centers. The five NHANES

continuous surveys consisted of 12 160, 13 156, 12 761, 12 862, and 12 943 individuals, respectively.

### *Measures*

#### *Body Mass Index (BMI)*

In NHANES I and II, height was measured in the mobile examination center by two health technicians using a special height scale and measured to the nearest inch and weight was measured using a self-balancing weight scale and measured to the nearest pound (68). In NHANES III and NHANES continuous, height was measured to the nearest 0.1cm using an electric stadiometer; and weight was measured to the nearest 0.1 kg using a digital scale (69). Body Mass Index was computed as weight (kg) divided by height squared ( $m^2$ ).

#### *Macronutrient Consumption*

The dietary interview component of NHANES provides detailed information for each participant. The data were used to estimate the total number of calories (kcal/day) and carbohydrates (g) from the foods and beverages consumed during the 24-hour period prior to the interview. Total number of carbohydrates was converted to percent of total calories.

In NHANES I and II, data on macronutrient consumption were obtained by a 24-hour recall method where each person was asked to report each food he had consumed on the day before the examination (midnight to midnight). An automated, microcomputer-based dietary interview and coding system known as the NHANES III Dietary Data Collection (DDC) System was used to collect all dietary recall data in NHANES III (70). For NHANES continuous, an automated data collection form, known as the computer-assisted personal interview (CAPI)

system, was used to estimate the total macronutrient intake from foods consumed during the 24-hour period prior to the interview (midnight to midnight) (71).

### *Physical Activity*

Physical activity levels were assessed using questionnaires. Since the questions assessing physical activity in NHANES I and NHANES II did not ask about frequency of physical activity, NHANES I and NHANES II were excluded from the physical activity and the fully adjusted analyses.

In NHANES III participants were asked if in the past month they participated in, and if so the frequency of their participation in activities including walking, jogging, bicycling or using an exercise bicycle, swimming, aerobics or aerobic dancing, other forms of dancing, calisthenics or exercises, gardening or yard work, and weight lifting during their leisure time. Individuals also had the option of listing up to 4 additional activities. In NHANES continuous, information about specific leisure-time activities was obtained by providing participants with a list of 60 activities and having them select what activities, if any, they did over the past 30 days and to report their frequency. Participants could also report any activities that were not on the list provided. For the purposes of this analysis, we used frequency as a measure of exercise frequency as exercise duration and intensity were not available in all surveys, and we wanted as long of a study period as possible.

### *Covariates*

Participants' age in years at the time of exam was re-coded. To ensure consistency throughout the surveys, the following demographic characteristics were recorded: race/ethnicity

(white or other), education level (high school or more/less than high school), and smoking status (current smoker, former smoker, non-smoker).

### *Measurement of Time*

Time was addressed using the survey variable to evaluate secular trends and associations. The survey variable was recoded from assigned cycle number into survey year (Appendix A). Specifically, time was denoted by the last year of the survey period and represented as such throughout the analysis.

### *Statistical Analysis*

Of the original sample of 125 250 individuals (NHANES I, NHANES II, NHANES III, and NHANES continuous surveys) 45 590 were included in the analyses examining secular trends in carbohydrate and caloric intake. Participants were excluded if they were not 20 to 74 years old or were missing data for age ( $n = 59\ 809$ ), or did not have a BMI between 18.5 and 50  $\text{kg}/\text{m}^2$  or had missing data for BMI ( $n = 47\ 731$ ). Participants were also excluded if they were pregnant ( $n=1\ 754$ ), or reported exceedingly low or exceedingly high ( $\geq 10\ 000$  kcal) or low ( $\leq 1000$  kcal) energy intakes ( $n=31\ 667$ ).

Examining secular trends in physical activity was limited to NHANES III and NHANES continuous (excluding NHANES 2007-2008) due to data availability. Of the original 74 646 individuals, 14 295 (7 329 males and 6 966 females) were included in the analyses. Participants were excluded if they were not 20 to 74 years old or were missing data for age ( $n = 42\ 175$ ), or did not have a BMI between 18.5 and 50  $\text{kg}/\text{m}^2$  or had missing data for BMI ( $n = 35\ 619$ ).

Participants were also excluded if they were pregnant (n=1 357), or were missing exercise frequency (n=41 762).

Means and standard deviations were computed for continuous variables (age, BMI, caloric intake, carbohydrate intake, and physical activity) for each survey year. Changes over time in BMI, caloric intake, carbohydrate intake, and physical activity were examined using trend analysis by simple linear regression. The total number of calories was converted to kcal/kg of bodyweight. Change in caloric intake and physical activity between surveys were computed by dividing the change in caloric intake or physical activity by the number of years between surveys (using the last year of the earlier survey and the first year of the later survey).

Trend analysis using multiple linear regression was conducted to determine secular changes in the association between physical activity, caloric intake, and carbohydrate intake with BMI over time. Main effects of relative caloric intake (kcal/kg), absolute caloric intake (total kcal), carbohydrate intake, physical activity, and time and the interactions with time on BMI were examined for males and females separately. Each analysis contained two models. Model 1 examined the effect of the independent variables (PA, calories, or carbohydrate intake 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, carbohydrate intake, and physical activity where appropriate. To facilitate graphical representation, the 25<sup>th</sup> and 75<sup>th</sup> percentiles were used as points of comparison between surveys for relative caloric intake (20 kcal/kg and 35 kcal/kg), total caloric intake (1000 kcal and 4000 kcal), carbohydrate intake (40% and 50% of total calories), and physical activity (frequency of 1 time/week and 10 times/week). Where the interactions were statistically significant ( $p < 0.05$ ),

the survey year variable was dummy coded to see which years were statistically different from one another. When the interactions were not significant, the analyses were conducted without the interaction term and the main effects of survey year and PA, calories or carbohydrate intake was examined. Data analysis was conducted using SAS software, version 9.3.

## Results

### *Secular Changes in BMI, Caloric Intake, Macronutrient Intake, and Physical Activity*

**Table 1** shows the sample characteristics for the eight NHANES surveys. There was a steady increase in BMI across time. In males, BMI increased from  $25.7 \pm 3.9 \text{ kg/m}^2$  in NHANES I (1971-1975) to  $28.6 \pm 5.4 \text{ kg/m}^2$  in NHANES 2007-2008, equating to a 11.3% increase in BMI across time ( $P < 0.0001$ ). In females, BMI increased from  $25.2 \pm 5.1 \text{ kg/m}^2$  in NHANES I (1971-1975), to  $29.4 \pm 6.6 \text{ kg/m}^2$  in NHANES 2007-2008, equating to a 12.9% increase across time ( $P < 0.0001$ ).

Daily caloric intake also increased from  $2330 \pm 943 \text{ kcal}$  in NHANES I (1971-1975) to  $2557 \pm 1048 \text{ kcal}$  in NHANES 2007-2008 for males (10.0% increase,  $P < 0.0001$ ) (**Table 1**). In females, daily caloric intake increased from  $1685 \pm 532 \text{ kcal}$  in NHANES I (1971-1975) to  $1917 \pm 694 \text{ kcal}$  in NHANES 2007-2008 (13.8% increase,  $P < 0.0001$ ). Daily caloric intake, relative to body weight, increased from  $29.3 \pm 0.3 \text{ kcal/kg}$  in 1975 to  $32.2 \pm 0.3 \text{ kcal/kg}$  in 2008 in males ( $P < 0.0001$ ), and  $24.9 \pm 0.3 \text{ kcal/kg}$  to  $28.1 \pm 0.2 \text{ kcal/kg}$  in females ( $P < 0.0001$ ) (**Figure 1**). Rate of change in daily caloric intake per year between NHANES I to NHANES 2007-8 surveys for males was: 0.7 kcal/kg, 0.3 kcal/kg, 0.0 kcal/kg, 0.1 kcal/kg, 0.3 kcal/kg, 0.3 kcal/kg, and 0.8

kcal/kg. For females they were as follows: 0.4 kcal/kg, 0.5 kcal/kg, 0.0 kcal/kg, 0.2 kcal/kg, 0.4 kcal/kg, 0.6 kcal/kg, and 0.1 kcal/kg.

There was an increase in absolute carbohydrate intake across time. In males, carbohydrate intake increased from  $246.3\text{g} \pm 110\text{g}$  in NHANES I to  $301.9\text{g} \pm 136\text{g}$  in NHANES 2007-2008, equating to a 22.6% increase across time ( $P < 0.0001$ ). In females, carbohydrate intake increased from  $191.2\text{g} \pm 74\text{g}$  in NHANES I (1971-1975) to  $239.1\text{g} \pm 98\text{g}$  in NHANES 2007-2008, equating to a 25.0% increase across time ( $P < 0.0001$ ). The percentage of calories derived from carbohydrate, also increased from  $42.6 \pm 0.3\%$  to  $48.2 \pm 0.2\%$  in men and from  $45.3 \pm 0.3\%$  to  $50.1 \pm 0.3\%$  in women ( $P < 0.0001$ ) (**Figure 1**).

Protein intake in males increased from  $89.1 \pm 36.3\text{g}$  in NHANES I (1971-1975) to  $93.3 \pm 36.5\text{g}$  in NHANES 2007-2008 ( $P < 0.0001$ ), whereas in females it increased from  $67.1 \pm 27.4\text{g}$  to  $70.7 \pm 28.2\text{g}$  ( $P < 0.0001$ ). Fat intake in males did not change significantly ( $P > 0.05$ ) but in females increased from  $68.2 \pm 28.2\text{g}$  in NHANES I (1971-1975) to  $71.9 \pm 32.7\text{g}$  in NHANES 2007-2008 ( $P < 0.0001$ ) (**Table 1**).

Finally, there was also a reported increase in physical activity across time. In males, exercise frequency increased from  $7.1 \pm 7.4$  times/week in NHANES III (1988-1994) to  $8.8 \pm 9.0$  times/week in NHANES 2007-2008, equating to a 23.9% increase across time ( $P < 0.0001$ ). The rates of change in physical activity per year between NHANES III and NHANES 2007-8 in males was: 0.3 times/week, 0.4 times/week, 0.2 times/week, and 0.1 times/week. In females, the frequency of exercise increased from  $5.5 \pm 6.0$  times/week in NHANES III (1988-1994) to  $9.2 \pm 10.5$  times/week in NHANES 2007-2008, equating to a 67% increase across time. The

rates of change physical activity per year between surveys for females were: 0.6 times/week, 0.1 times/week, 0.3 times/week and 0.2 times/week (**Figure 1**).

*Association between Caloric Intake, Carbohydrate Intake, & Physical Activity with BMI across Time*

The interaction of caloric intake (kcal/kg) and time on BMI was not significant in men (Model 1;  $P=0.6052$ ). **Figure 2** demonstrates a negative relationship in males between caloric intake (kcal/kg) and BMI within each survey year while adjusting for age, ethnicity, education, and smoking status ( $P<0.0001$ ). The main effects of time on BMI was significant, indicating that a given caloric intake was predictive of a greater BMI over time ( $P<0.0001$ ). In Model 2 after further adjusting for carbohydrate intake and physical activity, the interaction of caloric intake (kcal/kg) and time on BMI, became significant in men ( $P<0.0001$ ). The main effects of caloric intake (kcal/kg) and time on BMI were also significant ( $P<0.0001$ ). Specifically in 1988-1994, with adjustment for carbohydrate intake and physical activity, a caloric intake of 20 kcal/kg was predictive of a BMI of  $28.4 \text{ kg/m}^2$ , and a higher caloric intake of 35 kcal/kg was predictive of a lower BMI of  $26.8 \text{ kg/m}^2$ , equating to a  $1.6 \text{ kg/m}^2$  difference. Over time, the BMI became significantly higher and the difference between the predicted BMI for the two caloric intakes became marginally greater, such that in 2006, a 20 kcal/kg caloric intake was predictive of a BMI of  $30.6 \text{ kg/m}^2$  and a caloric intake of 35 kcal/kg was predictive of a BMI of  $28.2 \text{ kg/m}^2$ , equating to a  $2.4 \text{ kg/m}^2$  difference.

For females, the interaction of caloric intake (kcal/kg) and time and their main effects on BMI were significant in both models ( $P<0.0001$ ) wherein, BMI was negatively associated with caloric intake (kcal/kg) and the difference in predicted BMI for the two caloric intakes became

marginally greater over time ( $P < 0.0001$ ). Specifically in 1988-1994, a caloric intake of 20 kcal/kg was predictive of a BMI of  $34.1 \text{ kg/m}^2$ , and a caloric intake of 35 kcal/kg was predictive of a BMI of  $33.5 \text{ kg/m}^2$ , equating to a  $0.6 \text{ kg/m}^2$  difference (Model 2). In 2006, a 20 kcal/kg caloric intake was predictive of a BMI of  $34.8 \text{ kg/m}^2$  and a caloric intake of 35 kcal/kg was predictive of a BMI of  $34.1 \text{ kg/m}^2$ , equating to a  $0.7 \text{ kg/m}^2$  difference (**Figure 2**).

**Figure 3** demonstrates mixed results with respect to the association between total caloric intake (kcal) and BMI. For males, the interaction between total caloric intake (kcal) and time and the main effects of total caloric intake (kcal) on BMI were not significant for both models ( $P > 0.05$ ). The main effect of time on BMI, however, was significant in both models, indicating that a given total caloric intake (kcal) was predictive of a greater BMI over time ( $P < 0.0001$ ). Thus, a total caloric intake of 1000 kcal was predictive of a BMI of  $26.2 \text{ kg/m}^2$  in 1975 and  $28.8 \text{ kg/m}^2$  in 2008 (Model 1).

For females, the interaction between total caloric intake (kcal) and time ( $P = 0.0027$ ) and the main effect of total caloric intake (kcal) and time were significant (Model 1,  $P < 0.0001$ ). A total caloric intake of 1000 kcal/day and 4000 kcal/day were predictive of a BMI of  $25.5 \text{ kg/m}^2$  and  $23.4 \text{ kg/m}^2$ , respectively. In 2008, the overall BMI was higher, but the difference in predicted BMI diminished such that a total caloric intake of 1000 kcal/day was predictive of a BMI of  $28.2 \text{ kg/m}^2$  and a total caloric intake of 4000 kcal/day was predictive of a BMI of  $28.5 \text{ kg/m}^2$ . For Model 2, the interaction between total caloric intake (kcal) and time ( $P = 0.1737$ ), and the main effects of total caloric intake and time on BMI were not significant with further adjustment for carbohydrate intake and physical activity ( $P > 0.05$ ).

The interaction between carbohydrate intake (% of total calories) and time on BMI was not significant for Model 1 ( $P=0.3568$ ) nor Model 2 ( $P=0.2675$ ) for males. **Figure 4** demonstrates the significant negative association between carbohydrate intake (% of total calories) and BMI and the significant main effect of time for males ( $P<0.0001$ ) for both models. Specifically, in Model 2, a carbohydrate intake of 40% and 55% of total calories were predictive of a BMI of 27.8 kg/m<sup>2</sup> and 27.1 kg/m<sup>2</sup>, respectively in 1994, and 29.5 kg/m<sup>2</sup> and 28.8 kg/m<sup>2</sup> in 2006 ( $P<0.0001$ ).

Similar trends were observed for females. The interaction between carbohydrate intake (% of total calories) and time on BMI was not significant in either model ( $P>0.05$ ). However, the main effect of carbohydrate intake and time on BMI was significant in both models ( $P<0.0001$ ). Specifically, in Model 2, a carbohydrate intake of 40% and 55% of total calories were predictive of a BMI of 34.1 kg/m<sup>2</sup> and 33.45 kg/m<sup>2</sup>, respectively in 1994, and 34.8 kg/m<sup>2</sup> and 34.09 kg/m<sup>2</sup> in 2006 ( $P<0.0001$ ).

**Figure 5** illustrates a negative association between exercise frequency (per week) and BMI across time for males. The interaction between exercise frequency and time on BMI was not significant in either model ( $P>0.05$ ). The main effect of physical activity ( $P<0.05$ ) and time ( $P<0.0001$ ) on BMI was significant in both models. Specifically for males, when adjusting for caloric intake and carbohydrate intake, an exercise frequency of 1 time/week and 10 times/week were predictive of a BMI of 27.4 kg/m<sup>2</sup> and 27.3 kg/m<sup>2</sup>, respectively in 1994, and 29.1 kg/m<sup>2</sup> and 28.8 kg/m<sup>2</sup>, in 2006.

For females, the interaction between exercise frequency and time, and their main effects on BMI were significant for both models ( $P<0.05$ ). Specifically in 1994, when further adjusting

for caloric intake and carbohydrate intake, exercise frequency of 1 times/week was predictive of a BMI of 27.7 kg/m<sup>2</sup>, whereas an exercise frequency of 10 times/week was predictive of a BMI of 36.7 kg/m<sup>2</sup>, equating to a 9 kg/m<sup>2</sup> difference. Over time, BMI became significantly higher and the difference in predicted BMI for the two exercise frequencies got marginally greater with time (P<0.0001) such that in 2006, an exercise frequency of 1 time/week and 10 time/week were predictive of a BMI of 27.8 kg/m<sup>2</sup> and 37.6 kg/m<sup>2</sup>, respectively, equating to a 9.8 kg/m<sup>2</sup> difference.

## **Discussion**

Reduced physical activity and increased food intake are two of the most common explanations for the rising rates of obesity and are frequently cited as targets for potential public health interventions (72). Our results indicate that for a given caloric intake and physical activity level, BMI is increasing. We also observed a negative association between caloric intake and physical activity with BMI. Taken together, our results suggest that additional factors may be influencing how physical activity and caloric intake relate to obesity and how their relative contribution to obesity may have changed over time.

An increase in energy intake without a corresponding increase in energy expenditure often serves a possible explanation for the persistent positive energy balance and eventual weight gain in the US population (73,74). However, when examining the secular trends of caloric intake and physical activity, the data to support this notion are not definitive. The results of our study indicate that there has been a rise in both total caloric intake and the frequency of weekly physical activity in both males and females. Other studies also report similar increases in caloric intake (26,27), whereas some studies do not observe any changes (28), or report a

decrease in caloric intake over time (15). Research assessing secular trends of physical activity, although rare, have generally reported increases in physical activity from the 1980s through the 21<sup>st</sup> century (19,20,21,22). Nevertheless, the rise in obesity could be a result if the net increases in caloric intake are larger than the increased energy expenditure associated with the temporal changes in PA. While some studies have examined physical activity (19,20,21,22) and caloric intake (26,27,28,36) trends over time, they have not directly examined how these factors are independently associated with BMI, and whether this association has changed over time. The results of the present study indicate that for a given amount of caloric intake and physical activity, BMI has increased, suggesting that additional factors may be influencing how caloric intake and physical activity relate to BMI.

Our findings indicate that carbohydrate intake increased in both absolute and relative terms between 1975 and 2008. Some studies suggest that carbohydrate intake is positively associated with obesity (40, 75); whereas other studies fail to show any association (76,77). On the contrary, a study by Tucker et al suggests that carbohydrate intake is inversely related to obesity. Our findings are consistent with studies showing that carbohydrate intake promotes obesity, independent of excessive energy intake (36, 75). A high postprandial insulin response to high-glycemic index carbohydrate consumption may reduce fat oxidation and increase fat synthesis and storage, and has often been postulated as the underlying mechanism promoting obesity (40). Soft drinks are only one example of high glycemic foods that have shown dramatic increases in consumption (78). The increase in obesity and the concurrent increase in sugar-sweetened beverages (by 300% over 20 years) suggest that the consumption of sugar-sweetened beverages may be relevant for long-term weight management (78). Moreover, the secular increase in carbohydrate intake observed over our study time span suggests that carbohydrate

intake may be a contributing factor to the obesity epidemic and should be a target for public health interventions.

The changing relationship between diet and physical activity with obesity could be a reflection of other factors that have changed over time and have also been linked with obesity. These factors include a decrease in sleep duration, increased endocrine disruptors in the food chain, and a large increase in the use of prescription medications (79). The data shows that during the past several decades the average amount of sleep has decreased among US adults and children (51) and cross sectional and longitudinal studies suggest that sleep duration is inversely related to BMI (79,80). Endocrine disruptors have also been linked to obesity through multiple endocrine pathways (81,82). Endocrine disruptors are industrially produced substances that have increased in prevalence in the food chain (51). Moreover, the use of certain pharmaceutical drugs has been linked to increased weight. Medications including antipsychotics, antidiabetics, antihypertensives, and anticonvulsants have been known to induce weight gain and the evidence suggests that use of these drugs has dramatically increased in the past three decades. Specifically, antidiabetic, antihypertensive, and anticonvulsant prescriptions have increased nearly twofold from 1990 to 2001 (53,54). Since the aforementioned variables were not available and could not be accounted for in our study, it is possible that they influenced the changing relationship observed between diet and physical activity with BMI and could be playing an influential role in the rise in obesity.

The negative association found between caloric intake and BMI in our study is a striking finding that has also been observed in other studies (29). Many factors could be contributing to this paradoxical observation. Firstly, trends in energy consumption may be difficult to establish

as often times overweight or obese individuals are on calorie restricted diets. Specifically, a study by Mokdad et al. suggested that 45.0% and 65.7% of overweight and obese individuals are trying to lose weight and thus may not be providing an accurate representation of their normal dietary patterns (83). Measurement biases, specifically, people under-reporting their energy intake, have also been reported (84) and may contribute to the paradoxical observation that obese individuals appear to eat less than normal weight people. Our results showed that generally individuals consuming a greater number of calories had lower BMIs, suggesting that they may also have lower energy expenditure. Energy expenditure is largely determined by an individual's resting metabolic rate, but also by physical activity and the thermic effect of food. Indeed, we observed that obese individuals did less physical activity than the non-obese counterparts (data not shown). Moreover, a lower resting metabolic rate (relative to bodyweight) in obese individuals could partly be a consequence of weight cycling (85) and dieting (86). Weight cycling has been reported to result in lower skeletal muscle which can reduce resting metabolic rate (87). Moreover, many obese individuals on calorie restricted diets will also likely have a decrease in the thermic effect of food and an overall decrease in resting metabolic rate (88).

There are clear limitations to the results presented in this study. First, the NHANES data were obtained as multiple cross-sectional surveys making it 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. The NHANES surveys only include information on whether the participant is currently on any kind of diet to lose weight or for another health-related reason and if so, the type of diet since 2003-2004, and so we chose not to include it in our analysis as it would greatly reduce the time span we investigated.

The rise in physical activity noted from NHANES III to NHANES 1999-2000 must be interpreted with caution as there were methodological differences between the surveys. In NHANES III, respondents were asked if they had been in any of fifteen activities in the past month. Beginning in 1999-2000, respondents were provided with a list of approximately 30 activities and were asked to code all that apply. Consequently, trends detected by these surveys may be the result of differences in methods used rather than a reflection of real changes. However, when examining the secular trends in physical activity in our study, we saw a consistent rise in the BMI over time expected for a given amount of PA, with increases ranging from 0.1-0.4 times/week of exercise per year. Our findings suggest that the methodological differences between the surveys likely did not influence our conclusions.

We also urge cautious interpretation of our dietary results because of the changes in the methods used to collect the 24-h dietary recall in NHANES. For instance, recalls obtained in the NHANES I and II were limited to weekdays, whereas weekend days were included in the later surveys (61,63,66). When examining the difference in caloric intake (kcal/kg) between surveys, we noted that the greatest difference actually occurred between the NHANES II (1976-1980) and NHANES III (1988-1994) surveys. However, it is worthy to note that there was also an 8-year time gap between these two surveys, which could also be contributing to the large discrepancy observed. In our study, the overall trends with caloric intake were relatively consistent when expressed as a change per year, with increases ranging from 0.0-0.7 kcal/kg. Again, the rise in BMI over time expected for a given caloric intake was consistently positive, suggesting that our findings were not a consequence of the methodological differences between the surveys. Despite the aforementioned methodological shortcomings, the use of national survey data possesses advantages. Using such a large study population gives us the ability to capture secular trends in

caloric intake and physical activity. Having data dating back to the 1970s makes it possible to track trends over substantial periods of time. Moreover, the use of 24-hour dietary records possess several advantages such that they have little burden on the participant, no literacy requirements of the participants, do not alter the food intake behavior, and is a relatively rapid method of data collection (89,90,91,92).

The cross-sectional nature of the NHANES datasets restricted the statistical analysis that we could perform. Alternatively, future studies could look at growth curves using data that is available longitudinally. This approach will allow for the growth of obesity to be compared between those individuals who are physically active versus not active, for instance, providing an alternative means of examining the effect of the independent variable (physical activity, caloric intake, carbohydrate intake) on the dependent variable (BMI).

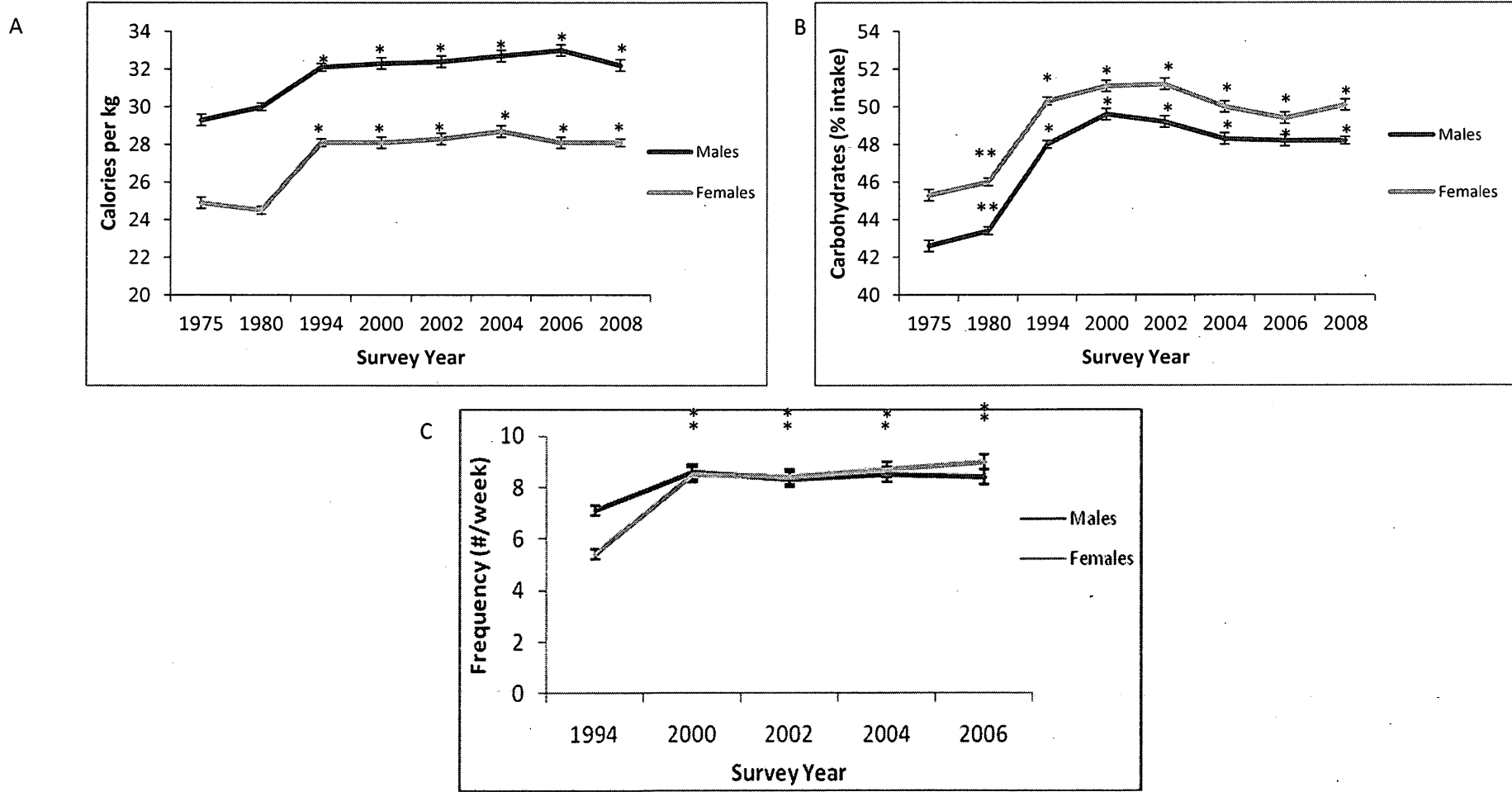
In conclusion, a given caloric intake and physical activity level was predictive of a greater BMI over time in our study. Our findings suggest that additional factors may be influencing how physical activity and dietary factors relate with obesity. We are not suggesting that the potential effects of physical activity and dietary factors should be discounted. However, public health practitioners and clinicians may need to address a broader range of influential factors, in addition to promoting healthy dietary choices and physical activity, to more adequately address the obesity epidemic.



Table 1: Sample characteristics across survey years

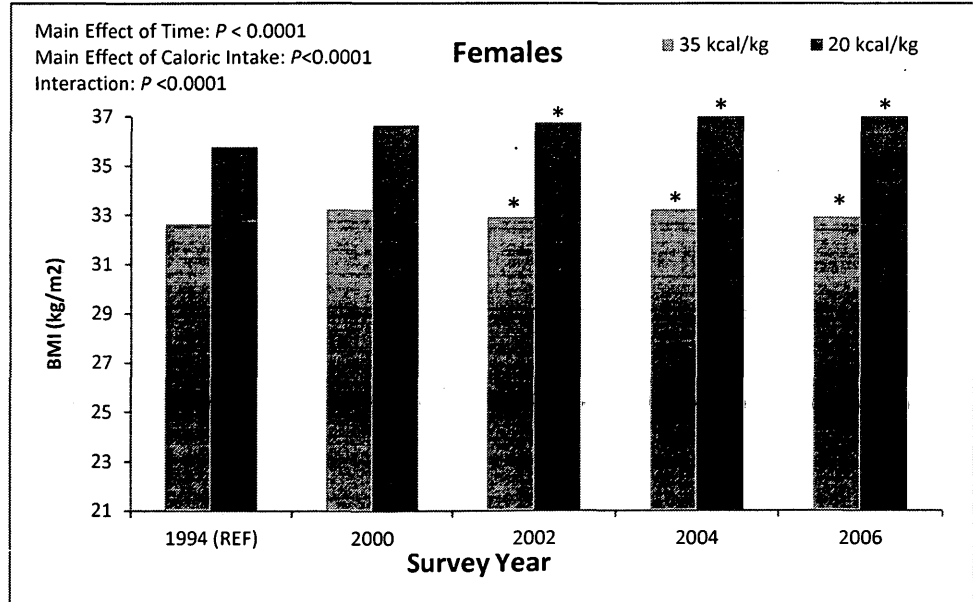
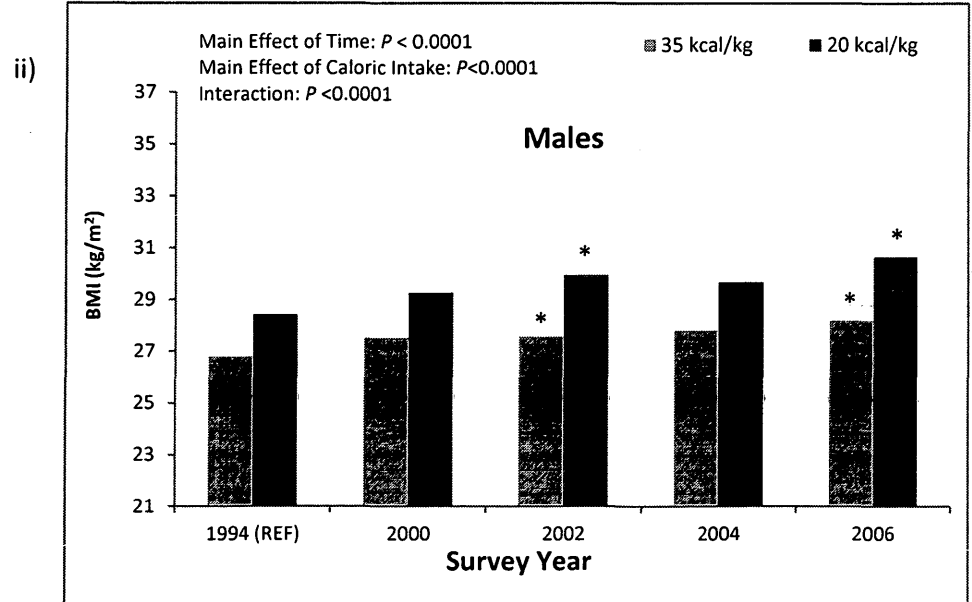
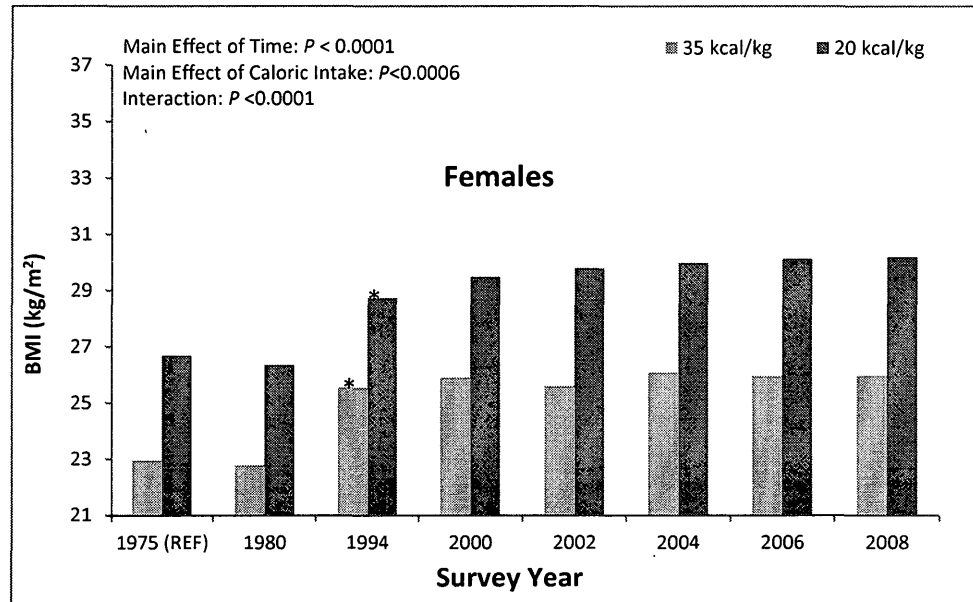
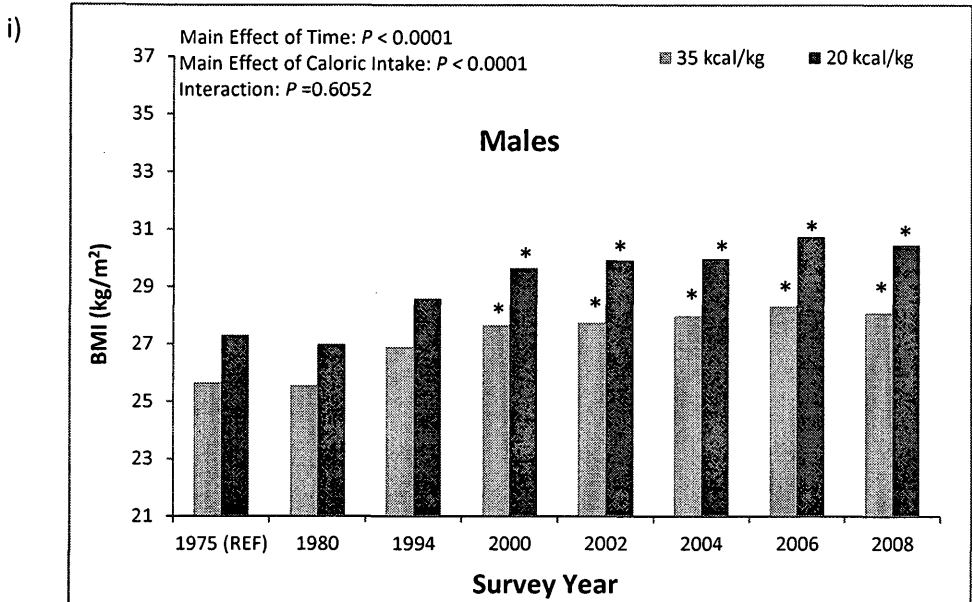
Characteristics	NHANES I (1971-1975)	NHANES II (1976-1980)	NHANES III (1988-1994)	NHANES 1999-2000	NHANES 2001-2002	NHANES 2003-2004	NHANES 2005-2006	NHANES 2007-2008
<b>Males (n)</b>	4492	5182	3343	1572	1775	1682	1765	2128
Age (years)	48.9 ±17.3	47.0 ±17.1	43.2 ±16.0	46.6 ±15.3	45.6 ±15.0	45.7 ±15.9	45.2 ±15.2	46.4 ±15.1
BMI (kg/m <sup>2</sup> )	25.7 ±3.9	25.5 ±5.2	26.9 ±4.6	29.0 ±6.5	28.1 ±5.1	28.2 ±5.2	28.7 ±5.3	28.6 ±5.4
Ethnicity (% white)	84.4	76.1	68.6	44.3	50.2	50.7	48.2	45.3
Total Caloric Intake (kcal/day)	2330 ±943	2419 ±1022	2622 ±1107	2559 ±1078	2622 ±1070	2660 ±1110	2674 ±1076	2557 ±1048
Carbohydrates (g/day)	246.3 ±110	256.6 ±116	308.2 ±138	313.8 ±144	318.0 ±144	317.9 ±153	315.0 ±136	301.9 ±136
Fat (g/day)	90.5 ±38.4	92.4 ±38.5	91.3 ±40.7	86.6 ±39.5	90.7 ±40.6	93.1 ±40.2	93.2 ±39.9	89.9 ±40.3
Protein (g/day)	89.1 ±36.3	89.2 ±36.3	94.6 ±37.7	92.2 ±37.0	93.4 ±37.5	95.8 ±37.3	95.5 ±37.3	93.3 ±36.5
Physical Activity (freq/wk)	--	--	7.1 ±7.4	8.9 ±12.7	8.6 ±8.8	8.8 ±10.5	8.8 ±9.0	--
<b>Females (n)</b>	5765	4525	3445	1444	1583	1476	1486	1933
Age (years)	43.2 ±16.9	47.5 ±17.1	42.0 ±15.3	46.5 ±15.3	45.4 ±15.0	46.6 ±15.5	45.3 ±15.1	46.9 ±14.9
BMI (kg/m <sup>2</sup> )	25.2 ±5.1	25.5 ±5.2	27.7 ±6.1	29.0 ±6.5	28.6 ±6.4	29.0 ±6.6	29.2 ±6.7	29.44 ±6.6
Ethnicity (% white)	82.5	74.8	65.8	40.6	50.3	50.1	47.0	43.8
Total Caloric Intake (kcal/day)	1685 ±532	1657 ±548	1937 ±734	1914 ±713	1943 ±674	1979 ±716	1939 ±694	1917 ±694
Carbohydrates (g/day)	191.2 ±74	190.1 ±74	241.2 ±95	245.1 ±106	247.9 ±96	245.2 ±100	238.1 ±94	239.1 ±98
Fat (g/day)	68.2 ± 28.2	66.9 ±27.7	73.1 ±34.3	69.3 ±32.0	72.2 ±31.7	75.1 ±33.2	73.2 ±32.1	71.9 ±32.7
Protein (g/day)	67.1 ±27.4	63.7 ±26.2	71.4 ±29.1	70.9 ±29.7	71.3 ±28.7	72.2 ±28.9	73.4 ±29.5	70.7 ±28.2
Physical Activity (freq/wk)	--	--	5.5 ±6.0	8.6 ±9.4	8.8 ±9.8	9.0 ±10.1	9.2 ±10.5	--

**Figure 1** –Secular trends in Caloric Intake (kcal/kg) (A), Carbohydrate Intake (% Intake) (B) and Exercise Frequency (C) in Males and Females



Significantly different from referent group (1975)\*( $p < 0.0001$ )\*\*( $p < 0.05$ ). Values are adjusted means +/- standard error mean. Adjusted for age, race, education, BMI, smoking status.

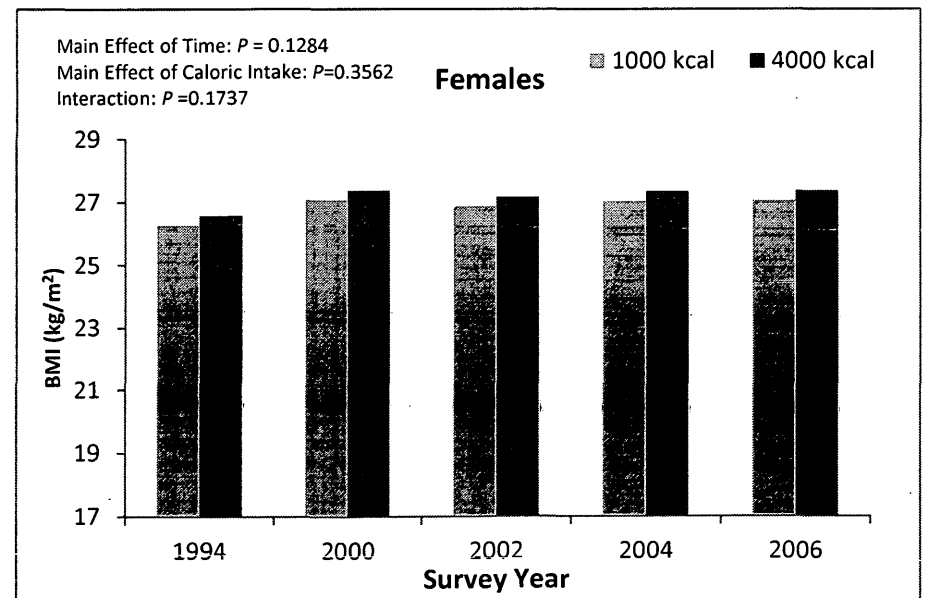
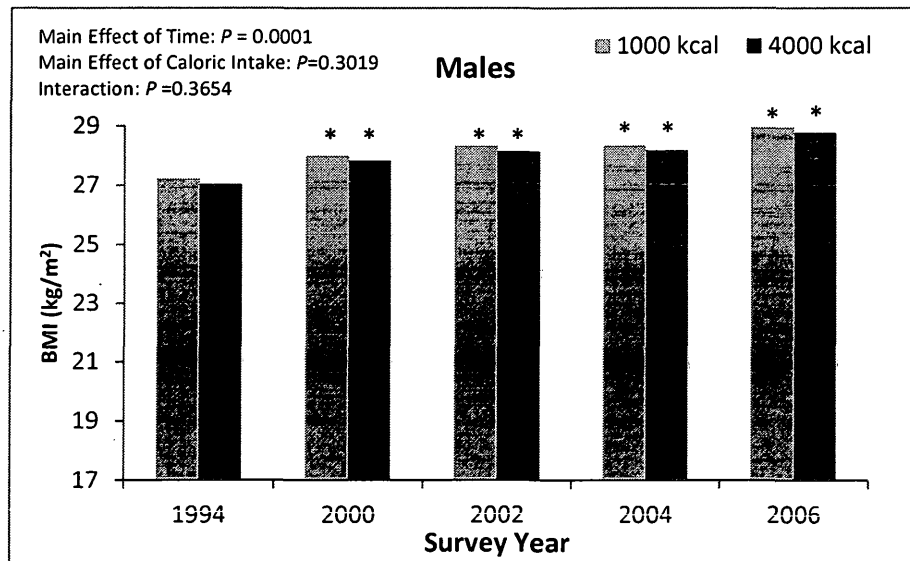
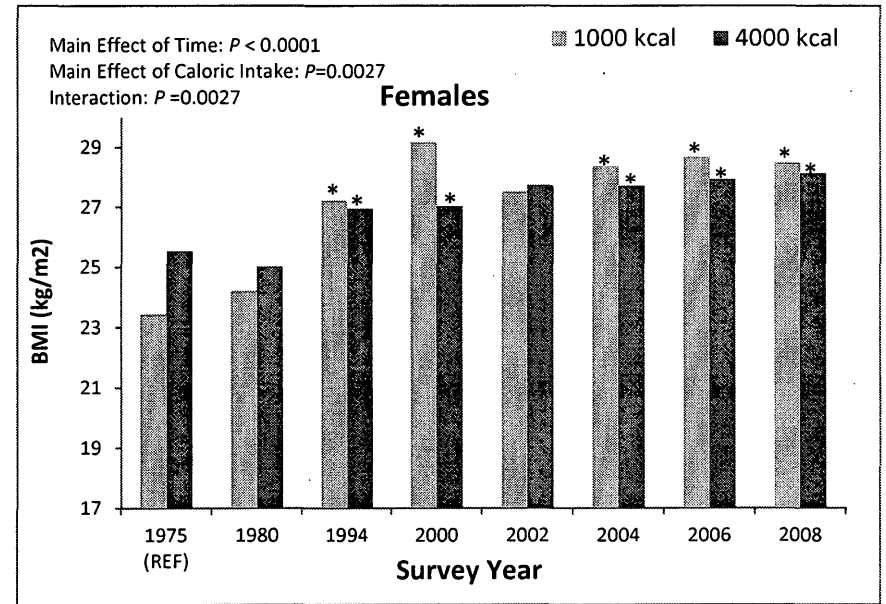
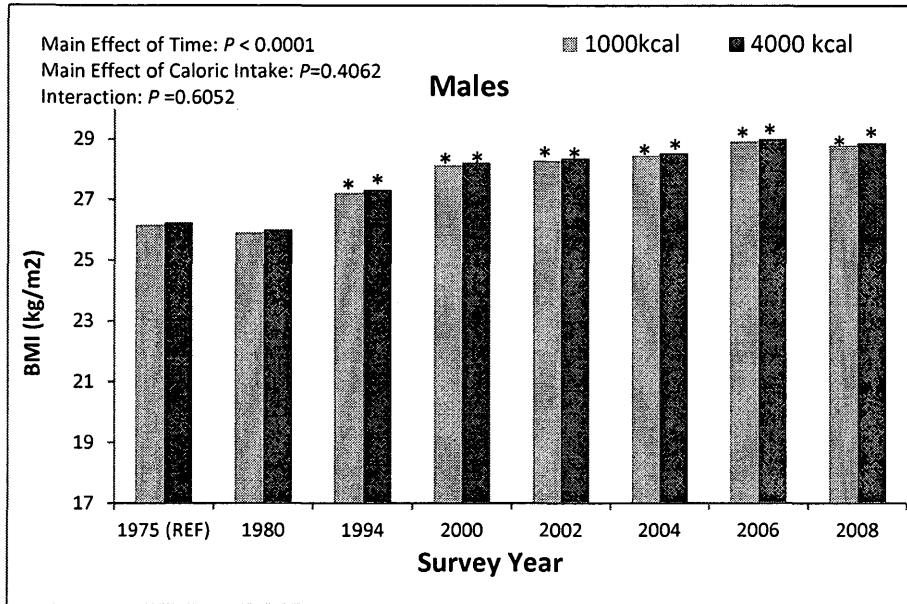
**Figure 2** – Secular trends in the relationship between Caloric Intake (kcal/kg) and BMI in Males and Females in (i) Model 1 (adjusted for age, sex, ethnicity, education level, and smoking status) and (ii) Model 2 (further adjusted for caloric intake, carbohydrate intake, and physical activity).



Values are predicted BMI for a white, non-smoking adult, 45 years of age, with at least a high school education. \*significantly different from 1975 (ref) and 1994 (ref).

**Figure 3** –Secular trends in the relationship between Caloric Intake (total kcal) and BMI in Males and Females in (i) Model 1 (adjusted for age, sex, ethnicity, education level, and smoking status) and (ii) Model 2 (further adjusted for caloric intake, carbohydrate intake, and physical activity).

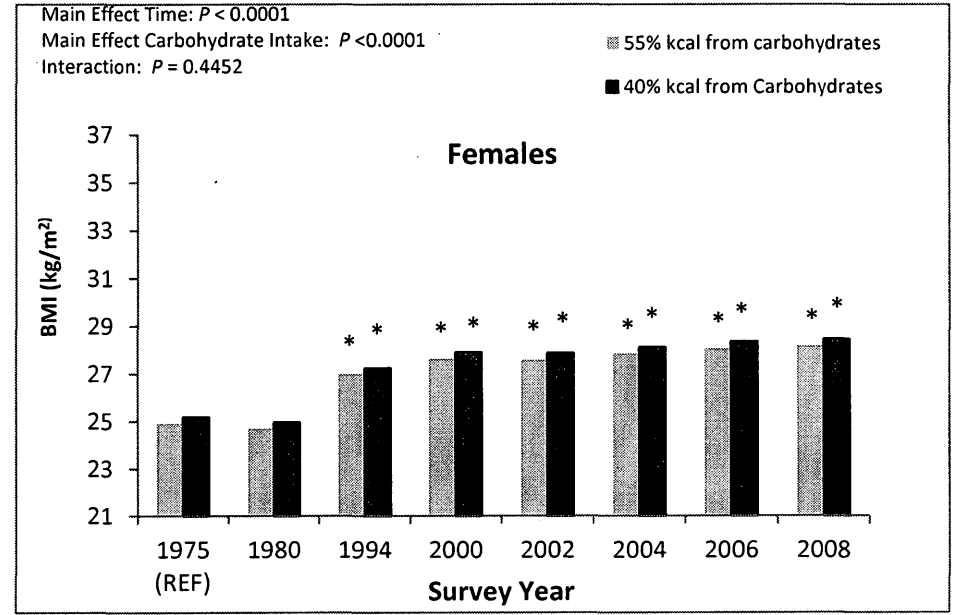
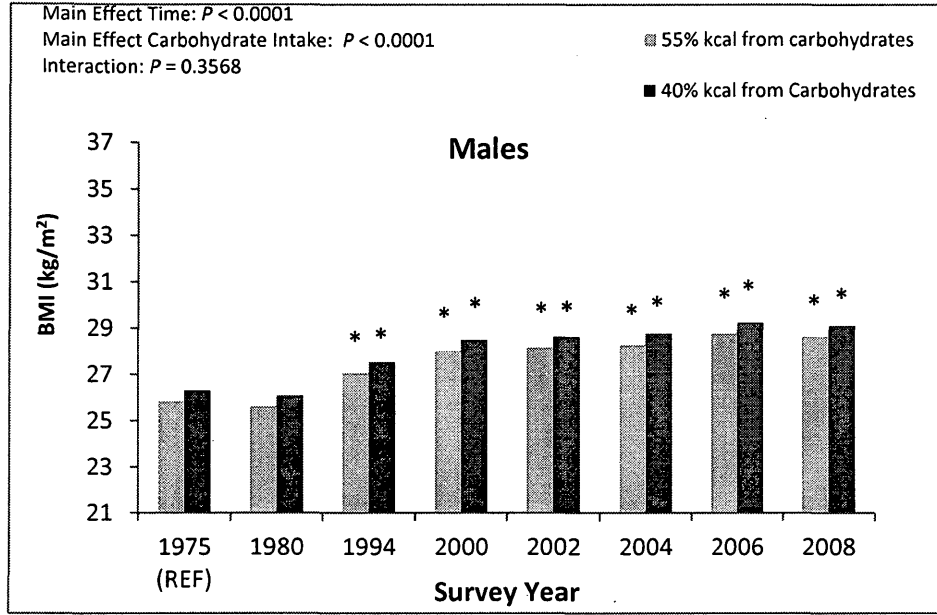
i)



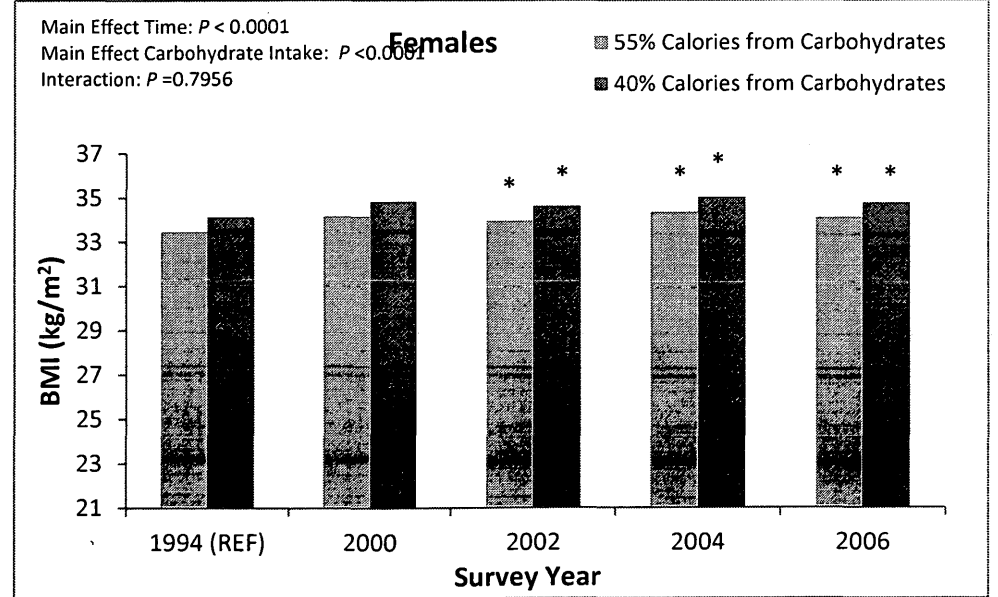
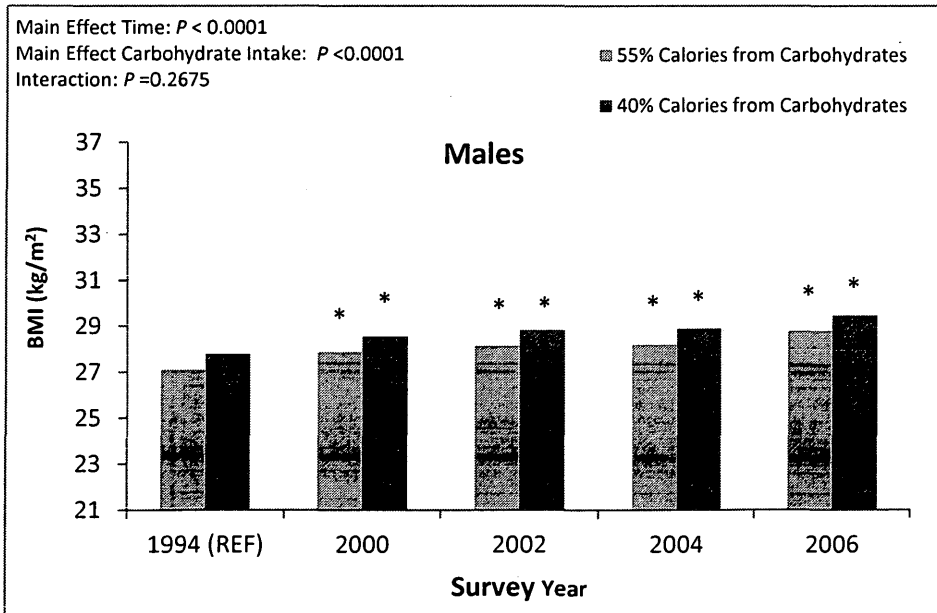
Values are predicted BMI for a white, non-smoking adult, 45 years of age, with at least a high school education. \*significantly different from 1975 (ref). \*\*For a given caloric intake BMI does not change

Figure 4 secular trends in the relationship between carbohydrate intake and BMI in males and females in (i) Model 1 (adjusted for age, sex, ethnicity, education level, and smoking status) and (ii) Model 2 (further adjusted for caloric intake, carbohydrate intake, and physical activity).

i)

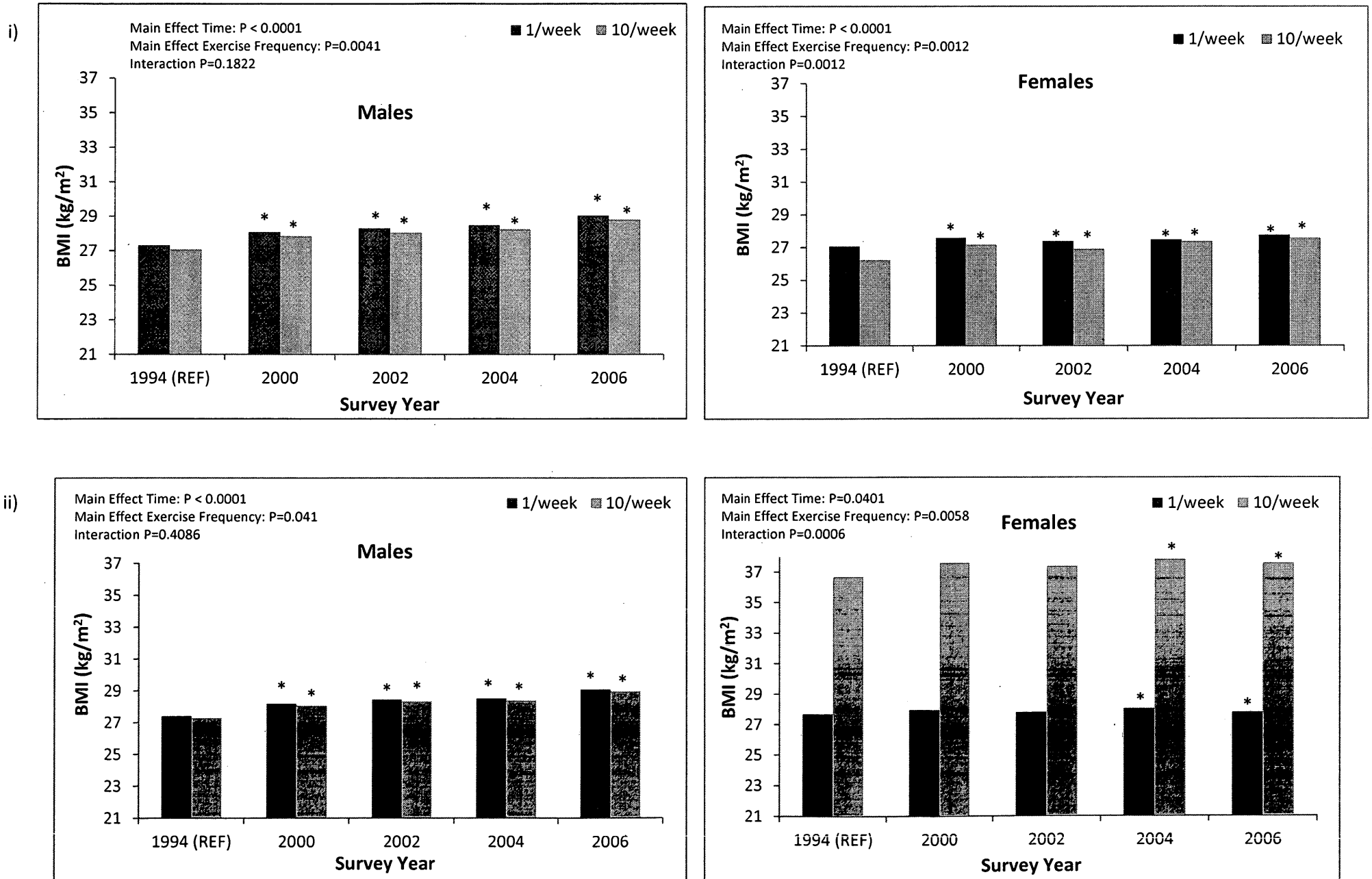


ii)



Values are predicted BMI for a white, non-smoking adult, 45 years of age, with at least a high school education. \*significantly different from 1975 (ref).

**Figure 5** –Secular trends in the relationship between exercise frequency (per week) and BMI in males and females in (i) Model 1 (adjusted for age, sex, ethnicity, education level, and smoking status) and (ii) Model 2 (further adjusted for caloric intake, carbohydrate intake, and physical activity).



Values are predicted BMI for a white, non-smoking adult, 45 years of age, with at least a high school education. \*significantly different from 1994 (ref).

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