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The associations between evening eating and quality of energy and macronutrients and obesity: the National Health and Nutrition Examination Survey (NHANES), 2003–2016

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Abstract

Background This study aimed to investigate the associations between evening eating and quality of energy and macronutrients and obesity among U.S. adults.

Subjects/methods This study adopted the data from the National Health and Nutrition Examination Survey (2003–2016), which involved a total of 27,911 participants. The differences in the ratios of energy and macronutrients with it is subgroups at dinner versus breakfast (ΔRatio) were categorized into quartiles. The differences in the consumption of 17 types of food at dinner versus breakfast (ΔFoods) were considered as continuous variables. Body mass index (BMI) and waist circumference (WC) were used to define general obesity (30.0 ≤ BMI < 40.0), morbid obesity (BMI ≥ 40.0), and abdominal obesity (WC > 102 cm for men or WC > 88 cm for women). Multiple logistic and linear regression models were developed.

Results After a variety of covariates were adjusted, participants in the highest quartile (higher energy/macronutrient intake at dinner than breakfast) of the ΔRatio in terms of energy were positively associated with morbid obesity compared with those in the lowest quartile ($OR_{\Delta Ratio\ of\ energy}$ 1.27; 95% CI 1.01;1.61) from fat ($OR_{\Delta Ratio\ of\ fat}$ 1.27, 95% CI 1.01;1.60); saturated fatty acids($OR_{\Delta Ratio\ of\ SFA}$ 1.27, 95% CI 1.01;1.59) and unsaturated fatty acids ($OR_{\Delta Ratio\ of\ USFA}$ 1.28, 95% CI 1.02;1.5). The highest quartile of the ΔRatio of low-quality carbohydrates was associated with increased odds of abdominal obesity ($OR_{\Delta Ratio\ of\ low\text{-}quality\ carbohydrates}$ 1.16; 95%CI 1.03–1.31). Moreover, the ΔRatio of low-quality carbohydrates was significantly positively associated with BMI (coefficient: 0.562, 95% CI: 0.217–0.907). ΔFoods, including whole fruits, other starchy vegetables, added sugars, poultry, dairy, and nuts, were positively associated with obesity.

Conclusions In conclusion, with this nationally representative sample of U.S adults, this study demonstrated that excessive intake of energy at dinner than breakfast during a day was associated with a greater risk of obesity, mainly from low-quality carbohydrates, fat, SFAs, and USFA. This study emphasized the importance of diet quality and evening eating in the prevention of obesity.

Keywords Energy, Macronutrients, Food sources, Energy distribution throughout a day, Obesity, Meal timing

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Background

Obesity is one of the greatest public health concerns because of its high prevalence and association with various chronic diseases [1–4]. High energy consumption is a relevant aspect of nutrition and may be a major reason for obesity [5–8]. A substantial amount of research is dedicated to strictly limiting total energy intake to achieve weight loss. However, such stringent energy restriction interventions can lead to low compliance or weight regain among populations. Therefore, there is an urgent need to establish a new, effective, and highly compliant dietary intervention approach to reduce the risk of obesity.

In addition to total energy intake, which refers to the quantity of dietary intake, the evening eating and quality of the diet are also key factors that have received widespread attention in the field of nutrition. Previous studies have shown that energy distribution affects obesity through disruption of clock gene expression [9, 10], and that the circadian clock gene plays a critical role in energy balance in mammals [11]. Moreover, breakfast skipping [12, 13], and late lunch [14] are associated with a greater risk of obesity, as well as lower overall diet quality and poorer cognitive performance [15, 16]. Researchers reported that breakfast skipping was related to weight gain as a result of overcompensation energy-dense high-fat foods later in the day [17]. On the other hand, observational studies reported that breakfast consumption was inversely associated with obesity and chronic disease through the regulation of glycemia, insulinemia, lipid metabolism, and possibly appetite [18]. Intake time can also be employed to prevent obesity and other metabolic pathologies [9]. Beyond the intake time, evidence suggested that the quality and food sources of macronutrients are also closely related to human health [19–21]. Limited research has been conducted on the quality and food sources of macronutrients simultaneously at dinner versus breakfast among adults. Between 1999 and 2016, there was a notable reduction in the proportion of energy consumed from low-quality carbohydrates among US adults, along with significant growth in the proportion of energy derived from high-quality carbohydrates, plant-based proteins, and polyunsaturated fats [22]. Taking into account the evidence presented, this study aims to consider both evening eating and dietary quality simultaneously to explore their relationships with obesity.

In the present study, we aimed to examine the associations of the evening eating and quality of energy, macronutrients, and foods with obesity among adults, and the data were collected from the National Health and Nutrition Examination Survey (NHANES, 2003–2016).

Methods

Study population

The NHANES is a stratified and multistage study with a nationally representative sample of the population of the U.S [23]. Detailed information was previously provided. A total of 71,058 participants were included from 2003–2004 to 2015–2016 in the NHANES. This study excluded participants without dietary data during the 7 cycles ($N=38{,}838$) and adults who were less than 20 years old ($N=2222$). The participants with extreme energy consumption [24] (< 500 kcal/day or > 3,500 kcal/day for women and < 800/day or > 4,200 kcal/day for men) ($N=1111$), pregnant women ($N=609$), and those with missing values for current drinking, current smoking, and BMI were excluded from this study ($N=367$). Finally, a total of 27,911 participants were included. The flow chart of the screening process for selecting eligible participants is shown in Supplementary Fig. 1.

The NHANES protocol was approved by the Ethics Review Board of the National Center for Health Statistics Research, and all participants provided informed consent.

Dietary assessment

The participants' food intake data for two nonconsecutive days were collected through 24-h dietary recall interviews. The first 24-h dietary recall was conducted in person, and the second one was conducted 3–10 days later via telephone. Dietary nutrients and energy consumption were estimated with the USDA's Food and Nutrient Database for Dietary Studies (FNDDS), and the mean values of energy, nutrient, and food consumption for day one and day two of the 24 h dietary recall were used in the analyses.

On the basis of the MyPyramid Equivalents Database 2.0 for USDA Survey Foods (MPED 2.0), the dietary intake component of the NHANES was integrated into 37 MyPyramid major groups and subgroups. Similar kinds of foods were combined into the same group according to the research published on JAMA [22]. Finally, a total of 4 main food groups and 17 subcategories were analyzed, which included high-quality carbohydrates including whole grains, legumes, whole fruits, and non-starchy vegetables; low-quality carbohydrates including refined grains, fruit juice, potato, other starchy vegetables, and added sugars; animal protein, including red meat, processed meat, poultry, marine food, dairy, and eggs; and plant protein, including whole grains, refined grains, legumes, nuts, and soy. Food sources of fat were not examined because they are similar to protein food sources, and the existing evidence on fat is focused on the types of fatty acids rather than food sources [25]. Details of the 4 main food groups are presented in Supplementary Table 1.

The participants' intake time at breakfast, lunch, and dinner was self-reported. Four snack patterns were determined on the basis of the timing of snack consumption, including 1) snack between breakfast and lunch, which was the self-reported food consumption between breakfast and lunch; 2) snack between lunch and dinner, which was the self-reported food consumption between lunch and dinner; 3) snack after dinner, which was the self-reported food consumption after dinner; and 4) none of the above, which means that the participants had never consumed foods other than three meals throughout a day [26].

Main exposure

The primary exposure variable in this study was the difference in the ratio of total energy and macronutrient consumption at dinner versus breakfast throughout the day. For example, the calculation method was as follows: $\text{Ratio}_{\text{energy}}$ at dinner = energy consumption at dinner/total energy; $\text{Ratio}_{\text{energy}}$ at breakfast = energy consumption at breakfast/total energy; ΔRatio of energy = $\text{Ratio}_{\text{energy}}$ at dinner—$\text{Ratio}_{\text{energy}}$ at breakfast; $\text{Ratio}_{\text{high-quality carbohydrates}}$ at dinner = high-quality carbohydrates consumption at dinner/total high-quality carbohydrates; $\text{Ratio}_{\text{high-quality carbohydrates}}$ at breakfast = high-quality carbohydrates at breakfast/total high-quality carbohydrates; $\Delta\text{Ratio}_{\text{high-quality carbohydrates}} = \text{Ratio}_{\text{high-quality carbohydrates}}$ at dinner – $\text{Ratio}_{\text{high-quality carbohydrates}}$ at breakfast. The macronutrients examined in this study included carbohydrates (high-quality carbohydrates and low-quality carbohydrates), fat (saturated fatty acids [SFAs] and unsaturated fatty acids [USFA, the sum of polyunsaturated and monounsaturated fatty acids]), and protein (animal protein and plant protein).

The second exposure was the difference in 17 subcategories of food consumption between dinner and breakfast(ΔFoods), for example, ΔWhole grains = whole grains consumption at dinner – whole grains consumption at breakfast.

Main outcome

In terms of outcomes, general, morbid, and abdominal obesity were determined by BMI and WC, respectively. Height and weight were measured via standardized procedures [27], in which participants were asked to remove their hair ornaments, jewelry, and other accessories from the head, and whether the back of the head, shoulder blades, buttocks, and heels made contact with the backboard was checked. The participants were weighed in kilograms with a digital weight scale, and they wore a standard MEC (mobile examination center) examination gown, which consisted of a disposable shirt, pants, and slippers. At the end of the examination, the weight of the participants was displayed in both kilograms and pounds. BMI was calculated as weight over height squared (kg/m^2) and used to define general obesity ($30.0 \leq \text{BMI} < 40.0$) and morbid obesity ($\text{BMI} \geq 40.0$) [28]. WC was measured to the nearest 0.1 cm at the high point of the right iliac crest at minimal respiration (cm) and was adopted to define abdominal obesity (WC > 102 cm for men or WC > 88 cm for women) [29]. A further detailed description of the examination protocol, quality control, and safety procedures can be found in the Anthropometry Procedures Manual via the NHANES website.

Assessment of covariates

Potential covariates were age (years old), sex (male/female), race/ethnicity (non-Hispanic white/non-Hispanic black/Mexican American/other), education level (< Grade 9/Grade 9–11/high school graduate/GED or equivalent/some college or Associate degree/college graduate or above), annual household income (< $20,000/$20,000—$45,000/$45,000—$75,000/ > $100,000), regular exercise (in a typical week, doing some moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate for at least 10 min continuously, yes/no), current smoker (yes/no), current drinker (had at least 12 alcohol drinks/1 year, yes/no), medicine use for lower blood sugar, medicine use for hypertension, medicine use for cholesterol, total intake of energy (kcal/day), fat (g/day), protein (g/day), SFA (g/day), dietary fiber (g/day), dietary cholesterol (mg/day), high-quality carbohydrates (cups/ounce/tsp equivalent) and animal protein (cups/ounce/tsp equivalent), daily total consumption of foods (cups/ounce/tsp equivalent), dietary supplements use (yes/no), breakfast skipping (energy consumption at breakfast was 0 kcal at the two days' 24-h dietary recall), sleep hours (hours), night shift workers (yes/no), time for breakfast (second), time for dinner (second), and diet quality calculated by the Alternative Healthy Eating Index (AHEI) [7].

Statistical analyses

All analyses incorporated dietary sample weights, stratification, and clustering of the complex sampling design to ensure nationally representative estimates according to NHANES analytic guidelines. In addition, to correct for measurement error, the absolute intakes of macronutrients and food sources per day were adjusted for total energy intake via the residual method in dietary estimates [30].

ΔRatio was categorized into quartiles. ΔFoods, foods at breakfast, and foods at dinner were considered continuous variables. Demographic characteristics, dietary nutrient intake, and anthropometric measurements are presented as the means ± standard errors for continuous variables and as percentages of categorical variables. The differences in $\Delta Ratio_{energy}$ by quartile were tested with general linear models for all variables after age adjustment.

Multiple logistic regression models were developed to examine the associations of the ΔRatio, ΔFoods, foods at breakfast, and foods at dinner with general obesity, morbid obesity, and abdominal obesity. Odds ratios (ORs) and 95% confidence intervals (CIs) are provided. Categorical variables were modeled as continuous variables through the assignment of the median value to each quartile to test linear trends. Models were adjusted for age, sex, ethnicity, education level, annual household income, regular exercise, current smoker, current drinker, the medicine used for lower blood sugar, the medicine used for hypertension, the medicine used for cholesterol, total intake of energy, fat, protein, SFA, dietary fiber, dietary cholesterol, high-quality carbohydrate, animal protein, dietary supplements use, breakfast skipping, and AHEI. Linear regression models were performed to examine the associations of the ΔRatio of energy and macronutrients with BMI (BMI was not log-transformed, since it was an approximately normally distributed, as shown in Supplementary Fig. 2). For the associations of ΔFood, food at breakfast, and dinner with obesity, the models were additional adjusted for the total daily intake of the food. General linear regression models were also adopted to examine the differences in macronutrient consumption during the day among participants.

This study further explored the substitution effects on obesity by replacing the food at dinner with 1 equivalent unit of food consumed at breakfast. Food consumption at breakfast and dinner was included in the same multivariable models as a continuous variable. For each substitution at dinner with breakfast, the difference between the β coefficients of the 2 variables was adopted to estimate the OR, and the variances and covariance of the 2 variables were adopted to estimate the 95% CI [31]. The differences in the estimates statistically predicted the substitution effects on the risk of general obesity, morbid obesity, and abdominal obesity. This substitution was interpreted as the association of decreasing 1 equivalent unit of food consumption at dinner and simultaneously increasing the intake at breakfast with obesity.

Sensitivity analyses

Nine sensitivity analyses were performed for the ΔRatio in terms of energy and macronutrients and obesity with multiple logistic regression models. (1) Participants who skipped breakfast were excluded. (2) Participants with dinner skipping were excluded. (3) Snack consumption between breakfast and lunch and snack consumption after dinner were considered (Δ = (dinner + snack after dinner) – (breakfast + snack between breakfast and lunch)). (4) Macronutrients in the energy-adjusted form were calculated [32] (macronutrients were measured in units per 1000 kcal per day, and details are shown in Supplementary methods 1). (5) Participants who were night shift workers or rotating workers from 2005 to 2010 were excluded. (6) Further adjustments were made with respect to sleep hours from 2005 to 2016. (7) We investigated the above associations among participants without excluding those with extreme energy intake. (8) The timing for breakfast and dinner should be adjusted. (9) Additionally, we investigated the above associations only adjusted for age and sex to avoid multicollinearity of dietary factors.

After Bonferroni correction for multiple comparisons in Cox regression models, a two-sided $P < 0.01$ was considered statistically significant. All analyses were performed with R 3.6.1.

Results

Demographic and dietary characteristics of participants

Table 1 shows the demographic and dietary characteristics of the participants aged over 20 years from NHANES 2003–2016 in this study ($N = 27{,}911$). Among the 27,911 participants, 8611 had general obesity, 1863 had morbid obesity, and 16,007 had abdominal obesity. Compared with participants in quartile 1, there were more younger participants, more people who were non-Hispanic white, more current smokers, and current drinkers in quartile 4, who had a greater waist circumference, and greater weight, lower dietary fiber, and lower dietary cholesterol ($P < 0.05$). No differences were found in BMI, regular exercise, the medicine used for hypertension, the medicine used for cholesterol across these quartiles ($P > 0.05$).

Time-related characteristics of participants

Table 2 shows the Time-related characteristics of the participants. Among the 27,911 participants, compared with the first quartile 1, the quartile 4 had lower consumption of energy at breakfast, ratio of high-quality carbohydrates at breakfast, ratio of low-quality carbohydrates at breakfast, ratio of animal protein at breakfast, ratio of plant protein at breakfast, earlier time for breakfast and dinner ($P < 0.05$). By contrast, compared with the first quartile 1, the quartile 4 had higher consumption of energy at dinner, ratio of high-quality carbohydrates at dinner, ratio of low-quality carbohydrates at dinner, ratio of animal protein at dinner, ratio of plant protein at dinner, and more breakfast skipping ($P < 0.05$).

Table 1 Demographic and dietary characteristics in terms of quartiles of $\Delta Ratio_{energy}$: NHANES, 2003–2016

Variables	Q1 (N=6971)	Q2 (N=6981)	Q3 (N=6987)	Q4 (N=6972)	P-value
Age, years	48.93 (0.37)	47.55 (0.36)	46.89 (0.32)	46.75 (0.36)	<0.001
Female, %	3772 (54.90)	3533 (51.58)	3514 (50.10)	3685 (53.11)	0.141
Non-Hispanic white, %	2459 (59.52)	3323 (70.43)	3620 (73.11)	3586 (71.96)	<0.001
Weight (kg)	80.26 (0.35)	82.59 (0.33)	83.04 (0.39)	82.70 (0.33)	<0.001
BMI, kg/m^2	28.57 (0.14)	28.84 (0.13)	28.79 (0.14)	28.83 (0.12)	0.174
Waist circumstance, cm	97.97 (0.33)	98.88 (0.32)	98.90 (0.36)	98.71 (0.30)	0.002
College graduate or above, %	1253 (23.72)	1759 (31.27)	1863 (32.61)	1665 (29.27)	<0.001
>$100,000 annual household income, %	592 (13.56)	877 (17.72)	985 (20.41)	864 (17.01)	<0.001
Regular exercise, %	1458 (25.12)	1602 (26.47)	1674 (27.17)	1619 (25.86)	0.205
Current smoker, %	1347 (20.89)	1573 (22.87)	1619 (22.48)	1801 (27.05)	0.012
Current drinker, %	4456 (67.78)	4739 (73.09)	4963 (75.58)	4860 (74.41)	0.003
Medicine use for lower blood sugar, %	823 (8.45)	666 (6.89)	615 (6.54)	579 (5.36)	0.081
Medicine use for hypertension, %	2047 (23.57)	1971 (23.48)	1829 (22.17)	1905 (22.92)	0.027
Medicine use for cholesterol, %	1429 (17.08)	1334 (16.85)	1269 (15.99)	1294 (17.10)	0.113
Total energy, kj/day	8242.44 (48.27)	8974.39 (47.73)	9047.90 (48.36)	8120.46 (45.72)	<0.001
Energy at breakfast, kj/day	2775.30 (23.50)	1738.47 (15.05)	1283.83 (15.46)	856.56 (13.53)	<0.001
Energy at dinner, kj/day	1354.34 (19.88)	2356.47 (16.91)	3425.89 (22.10)	5185.99 (35.05)	<0.001
Total fat, g/day	73.77 (0.62)	81.43 (0.57)	83.20 (0.67)	74.41 (0.62)	<0.001
Total protein, g/day	77.36 (0.62)	84.17 (0.60)	84.84 (0.57)	77.33 (0.62)	<0.001
SFA, g/day	24.00 (0.25)	26.55 (0.22)	27.40 (0.24)	24.28 (0.22)	<0.001
Dietary fiber, g/day	16.73 (0.19)	17.50 (0.16)	17.12 (0.20)	15.25 (0.17)	<0.001
Dietary cholesterol, mg/day	294.97 (3.58)	293.54 (3.22)	287.62 (3.01)	257.54 (3.12)	<0.001
Dietary supplements use, %	3503 (54.19)	3671 (55.39)	3680 (56.51)	3446 (51.82)	0.796
AHEI	52.67 (0.23)	56.19 (0.23)	56.63 (0.26)	52.56 (0.23)	<0.001
General obesity, %	2168 (29.20)	2134 (29.62)	2137 (29.98)	2172 (28.76)	0.932
Morbid obesity, %	374 (5.24)	462 (6.32)	500 (6.24)	527 (6.97)	0.001
Abdominal obesity, %	4072 (55.15)	3946 (55.56)	3965 (55.05)	4024 (56.08)	0.058
Percentage(%) energy from carbohydrate	49.75 (0.18)	48.75 (0.17)	47.96 (0.17)	47.57 (0.15)	<0.001
Percentage(%) energy from fat	33.95 (0.13)	33.95 (0.12)	34.53 (0.14)	34.35 (0.14)	<0.001
Percentage(%) energy from protein	15.95 (0.08)	15.95 (0.07)	15.97 (0.07)	16.21 (0.06)	0.019

All data analyses in the present study were based on weighted estimates with sample weights provided by the NHANES. Continuous variables are presented as the means (standard errors). Categorical variables are presented as n (%). *P* values were calculated by general linear model for all variables adjusted for age

BMI Body mass index (kg/m^2), *SFA* Saturated fatty acid, *AHEI* Alternative Healthy Eating Index, *Q* Quartile

Associations between the ΔRatio and general obesity, morbid obesity, and abdominal obesity

The associations of the ΔRatio with general obesity, morbid obesity, and abdominal obesity are shown in Table 3. After adjustment for a variety of covariates, the highest quartile of $\Delta Ratio_{low\text{-}quality\ carbohydrates}$ was significantly positively associated with abdominal obesity (OR 1.16; 95% CI 1.03–1.31). Even though $P_{for\ trend}$ was not significant, the highest quartile of $\Delta Ratio_{energy}$ (OR 1.27; 95% CI 1.01–1.61), $\Delta Ratio_{fat}$ (OR 1.27; 95% CI 1.01–1.60), $\Delta Ratio_{SFA}$ (OR 1.27; 95% CI 1.01–1.59), and $\Delta Ratio_{USFA}$ (OR 1.28; 95%CI 1.02–1.59) showed that there were greater odds of having obesity. No significant association was found for the $\Delta Ratio_{protein}$.

Associations between the ΔRatios of energy and macronutrients and BMI

The associations between the ΔRatio of energy and macronutrients and BMI are shown in Table 4. After adjustment for a variety of covariates, $\Delta Ratio_{low\text{-}quality\ carbohydrates}$ were significantly positively associated with higher BMI (coefficient: 0.562, 95% CI: 0.217–0.907). No linear trend was observed for the ΔRatio of energy and other macronutrients.

Associations between ΔFoods, foods at breakfast, and foods at dinner and general obesity, morbid obesity, and abdominal obesity

Figure 1 shows the associations between ΔFoods and general obesity, morbid obesity, and abdominal obesity.

Table 2 Time-related characteristics in terms of quartiles of $\Delta Ratio_{energy}$: NHANES, 2003–2016

Variables	Q1 (N=6971)	Q2 (N=6981)	Q3 (N=6987)	Q4 (N=6972)	P-value
Percentage(%) energy from breakfast	35.31(0.41)	20.10(0.21)	14.93(0.19)	11.08(0.17)	< 0.001
Percentage(%) energy from dinner	16.82(0.27)	26.90(0.21)	38.62(0.18)	65.83(0.42)	< 0.001
Ratio of High-quality carbohydrates at breakfast	0.27 (0.01)	0.22 (0.01)	0.20 (0.01)	0.16 (0.01)	< 0.001
Ratio of High-quality carbohydrates at dinner	0.31 (0.01)	0.35 (0.01)	0.40 (0.01)	0.48 (0.01)	< 0.001
Ratio of Low-quality carbohydrates at breakfast	0.30 (0.01)	0.22 (0.01)	0.19 (0.01)	0.16 (0.01)	< 0.001
Ratio of Low-quality carbohydrates at dinner	0.22 (0.01)	0.25 (0.01)	0.30 (0.01)	0.41 (0.01)	< 0.001
Ratio of animal protein at breakfast	0.23 (0.01)	0.14 (0.01)	0.11 (0.01)	0.09 (0.01)	< 0.001
Ratio of animal protein at dinner	0.42 (0.01)	0.47 (0.01)	0.53 (0.01)	0.63 (0.01)	< 0.001
Ratio of plant protein at breakfast	0.33 (0.01)	0.24 (0.01)	0.20 (0.01)	0.17 (0.01)	< 0.001
Ratio of plant protein at dinner	0.27 (0.01)	0.31 (0.01)	0.36 (0.01)	0.47 (0.01)	< 0.001
Sleep hours	7.09(0.05)	7.16(0.04)	7.14(0.03)	7.06(0.03)	0.200
Breakfast skipping, %	0(0)	611(7.33%)	1018(13.78)	2023(27.95)	< 0.001
Night shift workers, %	279(4.61)	273(4.31)	311(4.72)	300(4.51)	0.848
Time for breakfast, s	30,942.89(180.45)	29,876.81(116.29)	29,676.90(103.44)	29,779.23(129.24)	< 0.001
Time for dinner, s	67,022.14(126.28)	67,064.79(101.22)	67,061.24(105.40)	66,415.91(130.68)	< 0.001

All data analyses in the present study were based on weighted estimates with sample weights provided by the NHANES. Continuous variables are presented as the means (standard errors). Categorical variables are presented as n (%). *P* values were calculated by general linear model for all variables adjusted for age. Time for breakfast and dinner were converted into the number of seconds from midnight

Q quartile

For high-quality carbohydrate foods, ΔWhole fruits were positively associated with abdominal obesity (OR 1.08; 95% CI 1.01–1.17). For low-quality carbohydrate foods, ΔOther starchy vegetables were positively associated with general obesity (OR 1.41; 95%CI 1.02–1.95) and abdominal obesity (OR 1.53; 95% CI 1.10–2.15), respectively. Furthermore, ΔAdded sugars were positively associated with abdominal obesity (OR 1.01; 95% CI 1.00–1.02). Similarly, ΔFoods of animal protein including poultry and dairy, were positively associated with abdominal obesity ($OR_{\Delta Poultry}$ 1.04, 95% CI 1.01–1.08; $OR_{\Delta Dairy}$ 1.07, 95% CI 1.02–1.12). ΔFoods of plant protein including nuts were positively associated with general obesity (OR 1.06; 95% CI 1.00–1.14) and abdominal obesity (OR 1.06; 95% CI 1.00–1.13), respectively.

The associations of food consumption at breakfast with general obesity, morbid obesity, and abdominal obesity are shown in Supplementary Fig. 3. High-quality carbohydrate of whole fruits consumption at breakfast was related to lower odds of abdominal obesity (OR 0.82; 95% CI 0.73–0.94). For animal protein foods, poultry consumption at breakfast was negatively associated with general obesity (OR 0.89; 95% CI 0.81–0.98) and abdominal obesity (OR 0.88; 95% CI 0.82–0.96). Dairy consumption at breakfast was related to lower odds of abdominal obesity (OR 0.88; 95% CI 0.81–0.96). Moreover, plant protein foods of nut consumption at breakfast were associated with lower odds of abdominal obesity (OR 0.88; 95% CI 0.79–0.99). No association was detected for low-quality carbohydrate foods.

The associations of food consumption at dinner with general obesity, morbid obesity, and abdominal obesity are shown in Supplementary Fig. 4. The consumption of low-quality carbohydrates from other starchy vegetables at dinner was significantly positively associated with general obesity (OR 1.76; 95% CI 1.22–2.54) and abdominal obesity (OR 1.76; 95% CI 1.12–2.75). However, increased added sugars consumption at dinner was positively associated with morbid obesity (OR 1.02; 95% CI 1.00–1.04). For animal protein foods, poultry consumption at dinner was associated with increased odds of abdominal obesity (OR 1.04; 95% CI 1.00–1.08). No significant associations were detected between high-quality carbohydrates or plant protein foods and obesity.

Association of replacing 1 unit of food consumption at dinner with the equivalent unit of food consumption at breakfast with general obesity, morbid obesity, and abdominal obesity

Figure 2 shows the associations of decreasing the consumption of 1 unit of food at dinner and simultaneously increasing 1 unit of food consumption at breakfast with general obesity, morbid obesity, and abdominal obesity. Overall, it was found that a cup-equivalent decrease in whole fruit consumption at dinner with a cup-equivalent increase at breakfast was negatively associated with abdominal obesity (OR 0.88; 95% CI 0.77–1.00). A cup-equivalent decrease in non-starchy vegetable consumption at dinner with a cup equivalent increase at breakfast was negatively associated with general obesity (OR 0.87;

Table 3 Association between the Δ Ratio and general obesity, morbid obesity, and abdominal obesity

Δ Ratio	General obesity	Morbid obesity	Abdominal obesity
Energy			
Q1 (−1.78 to −0.02)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.02 to 0.15)	1.05 (0.94;1.17)	1.19 (0.96;1.48)	1.12 (1.01;1.25)
Q3 (0.15 to 0.33)	1.06 (0.95;1.19)	1.16 (0.91;1.48)	1.11 (0.98;1.26)
Q4 (0.33 to 2.00)	0.97 (0.86;1.11)	1.27 (1.01;1.61)	1.11 (0.97;1.27)
$P_{\text{for trend}}$	0.666	0.059	0.181
Carbohydrate			
Q1 (−1.87 to −0.09)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.09 to 0.09)	1.08 (0.98;1.20)	0.87 (0.67;1.12)	1.05 (0.93;1.17)
Q3 (0.09 to 0.27)	1.02 (0.91;1.14)	1.08 (0.85;1.36)	1.05 (0.93;1.19)
Q4 (0.27 to 2.00)	1.07 (0.95;1.21)	0.97 (0.76;1.24)	1.12 (0.98;1.28)
$P_{\text{for trend}}$	0.402	0.732	0.094
High-quality carbohydrate			
Q1 (−2.00 to −0.12)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.12 to 0.12)	1.02 (0.90;1.16)	1.16 (0.91;1.46)	1.00 (0.90;1.13)
Q3 (0.12 to 0.40)	0.93 (0.83;1.05)	1.02 (0.84;1.24)	0.97 (0.86;1.10)
Q4 (0.40 to 2.00)	1.08 (0.96;1.22)	1.13 (0.92;1.37)	1.08 (0.95;1.22)
$P_{\text{for trend}}$	0.300	0.436	0.246
Low-quality carbohydrate			
Q1 (−2.00 to −0.10)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.10 to 0.07)	0.94 (0.83;1.06)	0.94 (0.76;1.15)	0.98 (0.87;1.09)
Q3 (0.07 to 0.26)	1.04 (0.92;1.19)	0.81 (0.66;1.01)	1.07 (0.95;1.21)
Q4 (0.26 to 2.00)	1.06 (0.93;1.20)	1.04 (0.82;1.31)	1.16 (1.03;1.31)
$P_{\text{for trend}}$	0.180	0.847	0.004
Fat			
Q1 (−2.00 to −0.02)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.02 to 0.18)	0.97 (0.88;1.08)	1.06 (0.85;1.32)	1.12 (1.00;1.24)
Q3 (0.18 to 0.41)	1.07 (0.96;1.20)	1.04 (0.82;1.32)	1.12 (1.00;1.26)
Q4 (0.41 to 2.00)	0.93 (0.82;1.07)	1.27 (1.01;1.60)	1.12 (0.98;1.29)
$P_{\text{for trend}}$	0.517	0.044	0.121
SFA			
Q1 (−2.00 to −0.05)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.05 to 0.16)	0.95 (0.86;1.05)	1.03 (0.81;1.31)	1.08 (0.96;1.22)
Q3 (0.16 to 0.40)	1.06 (0.96;1.17)	1.07 (0.84;1.35)	1.12 (1.00;1.25)
Q4 (0.40 to 2.00)	0.90 (0.80;1.02)	1.27 (1.01;1.59)	1.12 (0.99;1.26)
$P_{\text{for trend}}$	0.259	0.017	0.072
USFA			
Q1 (−2.00 to −0.02)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (−0.02 to 0.19)	0.99 (0.90;1.09)	1.12 (0.87;1.45)	1.09 (0.97;1.23)
Q3 (0.19 to 0.42)	0.99 (0.89;1.11)	1.05 (0.81;1.34)	1.07 (0.96;1.19)
Q4 (0.42 to 2.00)	0.93 (0.82;1.06)	1.28 (1.02;1.59)	1.08 (0.95;1.23)
$P_{\text{for trend}}$	0.289	0.037	0.300
Protein			
Q1 (−2.00 to 0.02)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (0.02 to 0.23)	1.09 (0.97;1.22)	1.22 (0.97;1.55)	1.09 (0.97;1.23)
Q3 (0.23 to 0.46)	1.03 (0.91;1.16)	1.43 (1.15;1.77)	1.11 (0.99;1.24)
Q4 (0.46 to 2.00)	1.02 (0.90;1.16)	1.23 (0.97;1.55)	1.10 (0.97;1.25)
$P_{\text{for trend}}$	0.978	0.077	0.177

Table 3 (continued)

Δ Ratio	General obesity	Morbid obesity	Abdominal obesity
Animal protein			
Q1 (−2.00 to 0.13)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (0.13 to 0.38)	0.97 (0.87;1.09)	1.14 (0.94;1.38)	1.08 (0.96;1.22)
Q3 (0.38 to 0.59)	0.99 (0.88;1.10)	1.17 (0.96;1.43)	1.06 (0.94;1.20)
Q4 (0.59 to 2.00)	0.92 (0.82;1.03)	0.98 (0.81;1.19)	1.02 (0.90;1.16)
$P_{\text{for trend}}$	0.185	0.934	0.842
Plant protein			
Q1 (−2.00 to 0.10)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2 (0.10 to 0.10)	0.93 (0.84;1.04)	1.01 (0.82;1.25)	1.04 (0.93;1.17)
Q3 (0.10 to 0.32)	0.92 (0.82;1.04)	0.94 (0.73;1.19)	1.02 (0.91;1.15)
Q4 (0.32 to 2.00)	0.91 (0.82;1.02)	1.09 (0.89;1.34)	1.08 (0.97;1.21)
$P_{\text{for trend}}$	0.152	0.458	0.190

Adjustments included age, sex, ethnicity, income, education, regular exercise, smoke, alcohol intake, supplement use, medication use for lower blood sugar, medication use for hypertension, medication use for cholesterol, and total intake of energy, fat, protein, SFA, high-quality carbohydrate, animal protein, dietary fiber, dietary cholesterol, AHEI and breakfast skipping

SFA saturated fatty acid, *USFA* unsaturated fatty acid, *AHEI* Alternative Healthy Eating Index, *Q* quartile

Table 4 Association of the Δ Ratios of energy and macronutrients with BMI

Δ Ratio	Coefficient (95% CI)	*P* value
Energy	0.145 (−0.175;0.466)	0.371
Carbohydrate	0.074 (−0.223;0.370)	0.624
High-quality carbohydrate	−0.022 (−0.253;0.208)	0.848
Low-quality carbohydrate	0.562 (0.217;0.907)	0.002
Fat	0.138 (−0.133;0.409)	0.314
SFA	0.071 (−0.139;0.281)	0.505
USFA	0.127 (−0.151;0.405)	0.366
Protein	0.019 (−0.220;0.258)	0.875
Animal protein	0.027 (−0.223;0.276)	0.833
Plant protein	0.144 (−0.165;0.453)	0.357

Adjustments included age, sex, ethnicity, income, education, exercise, smoke, alcohol intake, supplement use, medication use for lower blood sugar, medication use for hypertension, medication use for cholesterol, and total intake of energy, fat, protein, SFA, high-quality carbohydrate, animal protein, dietary fiber, dietary cholesterol, AHEI, breakfast skipping; Q, quartile

SFA Saturated fatty acid, *USFA* unsaturated fatty acid, *AHEI* Alternative Healthy Eating Index

95% CI 0.77–0.98). In addition, a cup-equivalent decrease in the consumption of other starchy vegetables at dinner with a cup-equivalent increase at breakfast was related to morbid obesity (OR 0.28; 95% CI 0.09–0.88) and abdominal obesity (OR 0.52; 95% CI 0.27–1.00). Negative substitution associations of a tsp-equivalent of added sugars with general obesity (OR 0.99; 95% CI 0.98–1.00) and abdominal obesity (OR 0.98; 95% CI 0.97–0.99) were also observed. Similarly, the substitution of an ounce equivalent of poultry was negatively associated with general obesity (OR 0.89; 95% CI 0.83–0.95) and abdominal obesity (OR 0.87; 95% CI 0.82–0.93), respectively. The substitution of an ounce equivalent of dairy was negatively associated with abdominal obesity (OR 0.87; 95% CI 0.80–0.94). Furthermore, the substitution of an ounce equivalent of nuts was negatively associated with general obesity (OR 0.87; 95% CI 0.77–0.97) and abdominal obesity (OR 0.88; 95% CI 0.79–0.98).

Sensitivity analyses

After the exclusion of participants with breakfast skipping (Supplementary Fig. 5) and dinner skipping (Supplementary Fig. 6), the associations between the ΔRatios of energy and macronutrients and obesity were consistent with those from the primary analyses of the complete sample of participants. Moreover, similar results were observed when the snack consumption between breakfast and lunch as well as snack after dinner (Δ = (dinner + snack after dinner) – (breakfast + snack between breakfast and lunch))(Supplementary Fig. 7), and when considered in an energy-adjusted form (Supplementary Fig. 8). The results were consistent with those from the primary analyses of the complete sample of participants with the exclusion of shift workers in 2005–2010 (Supplementary Fig. 9) and additionally adjusted for sleep hours in 2005–2016 (Supplementary Fig. 10). The results were consistent with the primary results in Supplementary Fig. 11 and Supplementary Fig. 12 without excluding participants with extreme energy intake and additionally adjusted for the timing of breakfast and dinner, which suggests that the exclusion of these individuals, and the timing of breakfast and dinner did not influence the results. At last, the results were remained robust when

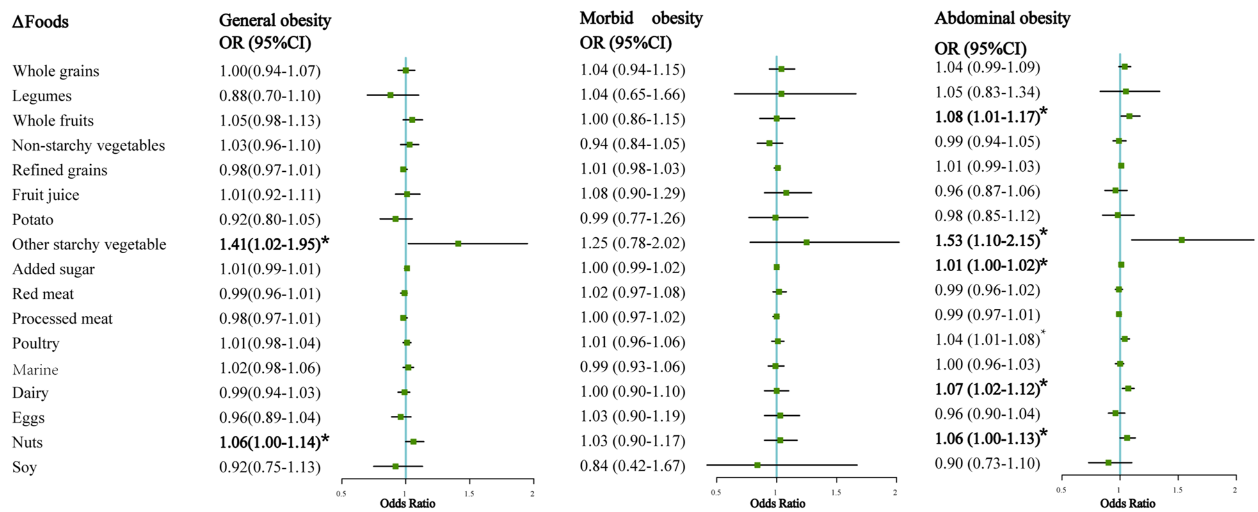

Fig. 1 Association of ΔFoods with general obesity, morbid obesity, and abdominal obesity

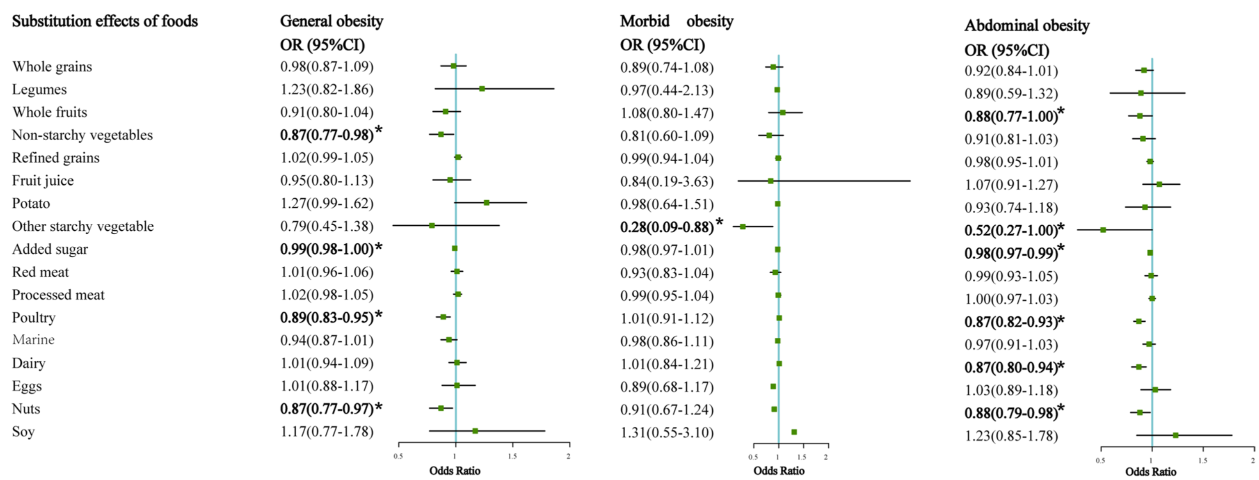

Fig. 2 Association of replacing 1 unit of food consumption at dinner with the equivalent unit of food consumption at breakfast with general obesity, morbid obesity, and abdominal obesity

the model only adjusted age and sex (Supplementary Fig. 13) to avoid multicollinearity.

Discussion

With this nationally representative sample of U.S. adults, this study demonstrated that excessive intake of energy at dinner than breakfast during a day was associated with greater risk of obesity, especially from low-quality carbohydrates, fat, SFAs, and USFA. Excessive intake of low-quality carbohydrates at dinner than breakfast was also associated with higher BMI. Overall, this study revealed that the quality and evening eating of carbohydrate and fat play important roles in prevention of obesity.

To the best of our knowledge, this is the first study to report the associations of evening eating and quality of energy intake, macronutrient, and food distribution during the day with obesity on the basis of nationally representative data. We found that excessive intake of energy at dinner than breakfast during the day was associated with a greater risk of obesity, from low-quality carbohydrates, fat, SFAs, and USFA. Multiple studies have reported that high-energy breakfast consumption is associated with body weight reduction [33, 34] and a lower average BMI [35]. Late-night eating has been associated with obesity in several cross-sectional studies [5, 36], which is consistent with the results of this study. Studies have shown that energy distribution throughout a day can affect body weight, blood pressure, inflammation, appetite, insulin sensitivity, and lipid profiles [37–39]. One possible mechanism could be that meal timing is related to markers of the circadian clock, aging, and autophagy [40]. Animal studies have also demonstrated diurnal rhythms in energy metabolism at both the molecular and whole-body levels [41–43]. Our findings indicate that consuming a high level of low-quality carbohydrates during dinner significantly increases the risk of obesity. However, when the total carbohydrate and high-quality carbohydrate contents were analyzed, this phenomenon was not observed, suggesting that both the quality and timing of carbohydrate intake are crucial for obesity. Consuming a large amount of low-carbohydrate food for dinner can lead to a sharp increase in blood sugar levels. However, it has been reported that insulin sensitivity has a circadian rhythm, peaking upon awakening. Two randomized clinical trials on women with obesity [44] or women with polycystic ovary syndrome [45] reported better glucose tolerance when participants consumed 50–54% of their calories at breakfast rather than having them at dinner. In the large breakfast groups of both studies, fasting glucose was reduced by 7–8%, fasting insulin was reduced by 22–53%, the glucose area under the curve (AUC) was reduced by 7–20%, and the insulin AUC was reduced by 28–42%, with higher insulin sensitivity indices. Therefore, consuming a large amount of low-carbohydrate food for dinner could result in the inability of insulin to break down excess blood sugar, thereby leading to obesity. Moreover, the ratios of macronutrients, including high-quality carbohydrates and low-quality carbohydrates, as well as the consumption of foods, including whole fruits, poultry, dairy, and nuts at breakfast were related to lower odds of obesity. Low-quality carbohydrate consumption at breakfast can result in the secretion of effective insulin and incretins, which may attenuate postprandial glycemic responses and decrease insulin requirements at lunch and dinner [46, 47]. Furthermore, the low-quality carbohydrate intake at breakfast could improve glucose tolerance during the day by benefiting the metabolic and incretin systems [48].

Excessive intake of any type of fat, regardless of SFA or USFA during dinner increases the risk of morbid obesity, confirming that the effect of the timing of fat intake is greater than its effect on quality. This finding was supported by a collection of mouse studies that have documented negative health outcomes, such as increased body fat, diminished glucose tolerance, abnormal blood lipid levels, and metabolic syndrome, when mice were fed a diet rich in fat, allowing them to eat as much as they wanted, during their rest period [49, 50]. Conversely, these studies also reported positive health benefits, such as reduced body weight, lower cholesterol, and enhanced insulin sensitivity, when the mice consumed an isocaloric high-fat diet at the beginning of their active phase [49, 50]. Although excessive fat intake at dinner (including both SFA and USFA) is associated with an increased risk of weight gain, our study results suggest that this intake does not show a significant correlation with the risk of general obesity ($30.0 \leq \text{BMI} < 40.0$). In contrast, excessive fat intake at dinner is more strongly associated with the risk of morbid obesity ($\text{BMI} \geq 40$). This phenomenon may be attributed to the fact that individuals with a $\text{BMI} \geq 40$ typically have more severe metabolic disruptions and endocrine issues, such as insulin resistance, fat accumulation, and higher levels of visceral fat [51], which make them more prone to further weight gain from excessive fat intake. In contrast, individuals with a BMI between 30.0 and 40.0, despite increased fat intake, may still be able to adapt their metabolic systems and fat storage mechanisms to this fluctuation, making them less likely to experience significant weight gain in the short term. Therefore, the relationship between fat intake and morbid obesity is more pronounced and involves the interaction of various factors, including genetics, metabolism, and lifestyle.

Moreover, this study revealed that a greater intake of foods, including whole fruits, other-starchy vegetables, added sugars, poultry, dairy, and nuts at dinner than breakfast was associated with a greater risk of obesity, which further supported the above associations. Notably, the consumption of whole fruits and nuts during the day can contribute to the prevention and management of overweight and obesity among adults [52, 53]. However, most types of whole fruits have high simple sugar contents, such as sucrose, fructose, and glucose [54]. Whole fruit consumption at dinner was positively associated with abdominal obesity in this study, possibly due to the overconsumption of simple sugars, which is one of the main causes of obesity and related diseases [55–57]. Furthermore, the overconsumption of high-calorie nut foods is often accompanied by excessive energy intake at dinner [58], which was associated with increased odds of obesity in the present study. In addition, it was shown that breakfast consumers had less abdominal obesity when their breakfast was composed of fruit, natural cereal flakes, nuts, and yogurt [59]. Furthermore, replacing 1 unit of the above food consumption at dinner with the same unit of food consumption at breakfast resulted in lower odds of obesity. It is worth noting that, dairy and nuts were considered beneficial on weight control in previous study [60]. Excessive intake of dairy products and nuts at dinner may contribute to obesity through several mechanisms. Dairy products, especially high-fat varieties such as whole milk, cream, and cheese, are calorie-dense and high in fat. Although certain components of dairy, like calcium and protein, can support metabolism and health, excessive consumption can lead to an energy surplus, promoting fat accumulation. Additionally, the lactose in dairy may impact insulin secretion and glucose metabolism, leading to fluctuations in blood sugar and encouraging fat storage [61]. The high caloric density of dairy products may contribute to weight gain, as even small portions can exceed energy expenditure. Similarly, nuts, which are rich in healthy fats (monounsaturated and polyunsaturated fats), are also highly energy-dense. While these fats were generally considered beneficial, their high caloric content can lead to an energy surplus when consumed in large quantities. Moreover, nuts may contribute to visceral fat accumulation, particularly when consumed at dinner, as the body's energy expenditure tends to decrease in the evening. As a result, the additional calories may not be expended and instead are stored as fat, increasing the risk of obesity.

This association was consistent with our primary analyses with further consideration of a series of traditional obesity-related dietary factors [31, 62, 63], as well as breakfast skipping, dietary quality, energy consumption status, shift or rotating workers, and sleep hours [64–67]. After re-inclusion of participants with extreme energy intake, the results were still consistent with the main results. Even if this small group of participants with extreme energy intake may have no impact on the associations, these participants were still removed to ensure rigor on the basis of previous literature [31]. Furthermore, the results were still robust when additional consideration of the timing of breakfast and dinner, and only adjusted for age and sex to avoid multicollinearity. Therefore, in dietary counseling, the emphasis should be placed not only on the quality of food but also on the duration of evening eating.

The results of this study suggest that both the evening eating and quality of macronutrients throughout a day need to be considered for dietary recommendations to prevent obesity, which provides certain theoretical significance for the establishment of dietary guidelines in the field of public health and suggests that people should attach importance to the quality and evening eating of macronutrients for the prevention of obesity.

Strengths and limitations

This study has several strengths. First of all, it was based on the nationally representative data from a well-designed study (NHANES). Second, the association remained robust when considering a series of traditional obesity-related dietary factors [31, 62, 63], as well as breakfast skipping, dinner skipping, snack consumption, dietary quality, shift workers, and sleep hours. Despite the obtained results, limitations still exist in this study. First, it was a cross-sectional study, and causal inferences could not be drawn. Second, measurement error was unavoidable for self-reported diet and other information, which may have resulted in an overestimation or underestimation of the association. Third, a series of confounders were considered, but residual confounders might remain.

Conclusion

In conclusion, with this nationally representative sample of U.S. adults, this study demonstrated that excessive intake of energy at dinner than breakfast during a day was associated with a greater risk of obesity, mainly from low-quality carbohydrates, fat, SFAs, and USFA. This study emphasized the importance of diet quality and evening time in the prevention of obesity.

Abbreviations

BMI	Body Mass Index
WC	Waist circumference
SFA	Saturated fatty acids
USFA	Unsaturated fatty acids
NHANES	National Health and Nutrition Examination Survey
AHEI	Alternative Healthy Eating Index
ORs	Odds ratios
Cis	Confidence intervals

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

All authors made a significant contribution to this article. WQ.W planned the work. WY.H carried out the statistical analysis. WY.H and RQ.S wrote and reported the work. All authors critically assessed and reviewed the paper and approved the version to be published. WQ.W are responsible for the overall content as guarantors.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The NHANES protocol was approved by the Ethics Review Board of the National Center for Health Statistics Research, and all participants provided informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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