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The association between adult asthma in the United States and dietary total energy intake: a retrospective cross-sectional analysis from NHANES

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Abstract

Background Epidemiological research links asthma progression to dietary nonallergic factors, particularly high-calorie intake. However, evidence supporting the relationship with total dietary calorie consumption remains scarce.

Objective This study aimed to explore the potential correlation between asthma occurrence and total dietary energy intake.

Methods A retrospective cross-sectional study of 21,354 US adults collected comprehensive participant data, including demographics, blood parameters, fatty acids, zinc, fiber intake, and asthma outcomes. Statistical analyses included interaction effects analysis, smooth curve fitting, and logistic regression.

Results Of 21,354 participants, 14.77% self-reported asthma diagnosis. After adjusting for confounders, odds ratios (OR) for asthma decreased with higher energy intake: Q2 (OR = 0.77, 95% CI: 0.69–0.86, $p < .001$), Q3 (OR = 0.66, 95% CI: 0.59–0.75, $p < .001$), and Q4 (OR = 0.61, 95% CI: 0.53–0.69, $p < .001$) compared to Q1 (< 17.73 kcal/kg/day). A non-linear (L-shaped) association between energy intake and asthma was observed ($p < .001$), with a critical threshold around 24 kcal/kg/day, supported by subgroup and sensitivity analyses.

Conclusion This study reveals an L-shaped trend between total energy intake and asthma in US adults, with a significant threshold at approximately 24 kcal/kg/day.

Keywords Cross-sectional study, Asthma, Nutrition, Total energy, L-shaped relationship

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Introduction

It has been speculated that during the 1950s, altered dietary habits, lead to a decline in the consumption of fruits, vegetables, and fish, which may be connected to the rising prevalence of asthma in western and Asia nations [1–3]. Maffeis et al. [4]. investigated the correlation between energy intake and expenditure in prepubertal male asthmatic patients. SHAHEEN et al. [5]. found that adults who consume more dietary antioxidants (apples and selenium) may protect themselves against asthma, and some people may see a reduction in the severity of their asthma if they consume more red wine.

Epidemiological research indicates a link between food components, particularly a high-calorie diet, and the development of asthma [3]. It is beneficial for children with mild-to-moderate asthma as they can use their dietary history to estimate their energy needs [4]. The correlation between an adult's total calorie intake and the likelihood of asthma development remains inadequately comprehended.

This cross-sectional study relies on data from the National Health and Nutrition Examination Survey (NHANES), ensuring a representative sample size. To enhance our understanding of asthma management and prevention, our study aims to evaluate the dose-response relationship and investigate the link between dietary total energy intake and asthma among adult volunteers in the United States.

Materials and procedures

The study population and the data source

This cross-sectional study utilized NHANES data spanning from 2009 to 2018, provided by the Centers for Disease Control and Prevention (CDC). NHANES, conducted by the National Center for Health Statistics (NCHS), employs a stratified, multistage probability cluster sampling methodology to assess the nutritional status and overall health of the non-institutionalized US population [6–8]. The NHANES encompasses a broad spectrum of data collection techniques, including comprehensive health and demographic information obtained from screenings, house calls, and laboratory evaluations conducted at mobile examination centers (MECs) [7]. The NHANES study protocol was approved by the NCHS research ethics review board, and at the time of enrolment, participants provided written informed permission [6, 9]. The Institutional Review Board did not require further permission for the current secondary analysis. This study adhered to the reporting standards outlined in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The NHANES dataset used in this investigation is accessible at the NHANES website (https://www.cdc.gov/nchs/nhanes/index.htm). A total of 49,693 individuals finished the interviews. Individuals younger than 20 years old (n=20858) were excluded. Additionally, individuals (n=3488) who lacked complete information about their dietary intake of total energy intake and asthma were also not included.

Asthma

In the NHANES database, we defined asthma status based on responses to the question [7] "Has a doctor or other health professional ever told you that you have asthma?" A response of "Yes" indicates asthma, while a response of "No" indicates non-asthma. The accuracy of self-reported asthma status has been validated. Furthermore, we referenced relevant literature, confirming that it is feasible to determine asthma and non-asthma patients based on self-reported questionnaire responses [7, 10–16].

Dietary total energy intake

The NHANES dietary evaluation utilized a completely computerized memory system with standardized inquiries and response options tailored specifically for food-related topics [7]. This method was adopted to guarantee a thorough and detailed gathering of dietary data. The precise nutritional values for each participant were determined using both the Automated Multiple-Pass Method (AMPM) and the Continuing Survey of Food Intakes by Individuals (CSFII) (https://fdc.nal.usda.gov/) [18, 19]. The NHANES Dietary Interviewers Procedure Manuals [20] is a thorough manual that includs detailed information on the dietary survey methodology [7].

24-hour dietary recall interview were performed twice in order to assess the dietary intake of total energy intake. The interviews were conducted face-to-face at the MEC [20]. The average daily consumption (kcal/kg/day) [21] of total energy intake was computed by averaging the results of two interviews, adjusting for participant weight, and excluding those with incomplete participant data. Finally, participants were divided into four groups based on total energy intake (kcal/kg/day) quartile amounts: Q1 (<17.73 kcal/kg/day; n=5339), Q2 (17.73–24.52 kcal/kg/day; n=5338), Q3 (21.52–33.29 kcal/kg/day; n=5338), Q4 (>33.29 kcal/kg/day; n=5339).

Covariates

In accordance with the pre-existing literature requirements [7, 22], a range of possible factors were evaluated. The following variables were chosen: gender, age, ethnicity and race, hemoglobin count, ratio of income to poverty(PIR), percentage of eosinophils, white blood cell count, n-6 polyunsaturated fatty acids (n-6 PUFAs), n-3 polyunsaturated fatty acids (n-3 PUFAs), zinc, total fiber, and familial asthma. Particularly, the following racial and ethnic categories were noted: non-Hispanic White, non-Hispanic Black, Mexican American, and other Hispanic

[7, 23]. As per a report from the US government, family income was categorized into three groups using the Poverty Income Ratio (PIR), which is obtained by dividing the family's (or individual's) income by the poverty threshold for the survey year. These groups encompassed the subsequent income brackets: low (PIR ≤ 1.3), medium (PIR > 1.3–3.5), and high (PIR > 3.5) [7, 24]. BMI < 25, BMI 25–30, and BMI ≥ 30 are the categories for BMI. The smoking status was classified as never smokers (less than 100 cigarettes smoked), current smokers, and former smokers (quit after smoking more than 100 cigarettes) based on classifications from previous literature [25]. The three categories of physical activity were: sedentary, moderate (at least 10 min of movement in the previous 30 days that produced only mild to moderate sweating or an increase in heart rate or breathing), and vigorous (at least 10 min of activity in the previous 30 days that produced profuse sweating or an increase in heart rate or breathing). At the NHANES MEC, the Beckman Coulter DxH 800 device was utilized to evaluate both blood cell distribution and conduct a complete blood count (CBC) on participants' blood samples. This included measuring hemoglobin (HGB), the proportion of eosinophils (EOPC), and the white blood cell count (WBC). Covariates with missing data were not included (n=3981). Lastly, 21,354 people were included in the analysis.

Statistical analysis

The statistical programs IBM SPSS, version 25.0 (IBM-Corp., Armonk, N.Y., USA), and Free Statistics, version 1.9, were used for all analyses. The independent and chi-squared tests were carried out to examine the differences in continuous and categorical variables, respectively. Given that only the available data was used to set the sample size, no prior estimates of statistical power were produced. For each participant, descriptive statistics were utilized, and two-tailed testing was done with a 5% threshold was used to determine significance.

We employed these logistic regression models to ascertain the association between asthma and total energy consumption (kcal/kg/day). Three adjustment models were constructed for the multivariate logistic regression analysis: Model 1: age, gender, race and ethnicity, familial asthma, physical exercise, smoking status, and PIR. Model 2: Model 1, white blood cell count, percentage of eosinophils, hemoglobin count, and Vitamin D. Model 3: Model 2, n-3 polyunsaturated fatty acids (n-3 PUFAs), n-6 polyunsaturated fatty acids (n-6 PUFAs), total fiber, and zinc.

Restricted cubic spline (RCS) curves were used to investigate the dose-response relationship between total dietary energy intake and asthma, and confounders were adjusted according to logistic regression model 3, which showed a nonlinear relationship between energy intake and asthma. Therefore, we further adjusted the variables in Model 3 using a generalized additive model (GAM), which first used a recursive algorithm to identify 24 mg/kg/day as the threshold for total energy intake, and then used a two-piece logistic regression model to assess effect sizes and confidence intervals on the left and right sides of the threshold for total energy intake. Furthermore, after controlling for Model 3 variables, we investigated the threshold relationship between dietary total energy consumption and asthma using a logistic regression model.

Additionally, we assessed potential modifications of this association based on BMI categories, race and ethnicity, sex, physical exercise, smoking status, and familial asthma. We utilized multivariate logistic regression analysis, incorporating likelihood ratio tests to investigate interactions.

Results

Examine the base parameters and the population

Between 2009 and 2018, 49,693 participants in this study had satisfactory interviews. We eliminated those under the age of twenty (20,858), those without completed asthma questionnaires (n=25), and those lacking complete dietary energy information (n=3463). Data with missing variables were also excluded (n=3993). As a result, 3154 (14.77%) of the 21,354 participants developed asthma in the final analysis (Fig. 1). Based on dietary total energy levels, Table 1 shows the study population's characteristics. The mean age of the participants was 49.2 ± 17.5 years; 11,010 (51.5%) were female; 9,037, 42.3% of them, were identified as non-Hispanic white; 16,535, 77.4% of them, were over 65. Age, ethnicity and race, sex, PIR, BMI, physical exercise, smoking status, familial asthma, vitamin D, zinc, n-6 and n-3 PUFAs, total fiber, percentage of eosinophils, WBC, and hemoglobin all showed statistically significant differences on dietary total energy levels (Q1, Q2, Q3, Q4) (Table 1).

Association between Asthma and total energy intake from diet

After eliminating potential confounding factors, we discovered a noteworthy inverse relationship between dietary total energy intake and asthma through multivariate logistic regression analysis. The quartiles of the total energy consumed through diet were identified. The second group Q2 had adjusted odds ratios (OR) for asthma of 0.77 (95% CI: 0.69–0.86, p<.001) (17.73–24.52 kcal/kg/day). In group Q3, the value was 0.66 (95% CI: 0.59–0.75, p<.001) kcal/kg/day, and 0.61 (95% CI: 0.53–0.69, p<.001) in the fourth group Q4 (>33.29 kcal/kg/day) compared to individuals in the group Q1 (<17.73 kcal/kg/day) with the lowest overall energy consumption (Table 2).

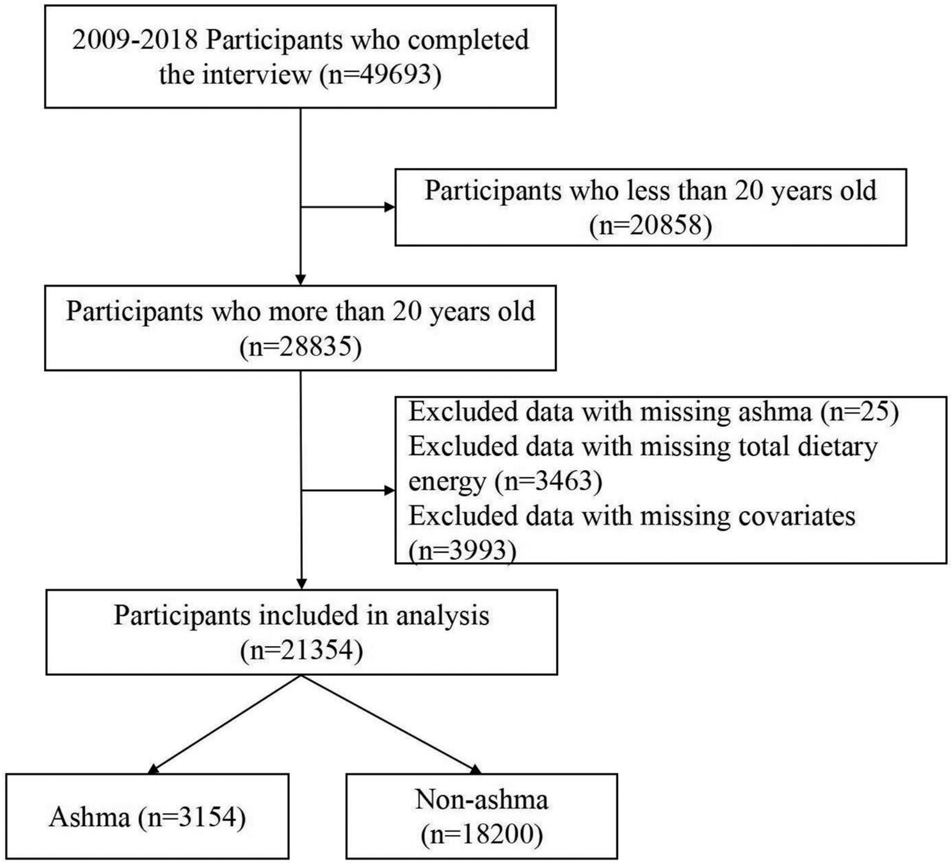

Fig. 1 Study's flow diagram

Interestingly, restricted cubic spline analysis revealed a non-linear L-shaped curve ($p<.001$) when exploring the relationship between total energy intake from the diet and asthma, as depicted in Fig. 2. We further adjusted the variables in Model 3 using a generalized additive model (GAM), which first used a recursive algorithm to identify 24 mg/kg/day as the threshold for total energy intake, and then used a two-piece logistic regression model to assess effect sizes and confidence intervals on the left and right sides of the threshold for total energy intake. On the left side of the threshold, each unit increase in energy intake was associated with a 3.1% reduction in the odds of developing asthma (OR=0.959, 95% CI: 0.946–0.973, $p<.001$). The effect size (OR) on the right side of the threshold was 0.996 (95% CI: 0.99–1.003, $P=.2477$) (Table 3).

Sensitivity analysis and stratified analysis depending on additional factors

When stratified by race and ethnicity, BMI, or familial asthma status, multiple subgroups stratified analyses showed no significant correlations in any subgroup (Fig. 3). But for asthma and sex (P for interaction less than 0.05), a planned subgroup analysis observed a significant relationship (Fig. 3).

Discussion

According to our cross-sectional study, total energy intake and asthma risk in Americans having an L-shaped relationship with fashion. The risk of having asthma is linked to a 1.7% decrease for every kilogram per day increase in total calorie consumption, when the daily energy intake is less than 24 kcal/kg/day. When total energy intake exceeds 24 kcal/kg/day, there is no significant correlation between asthma risk and total energy intake. These findings indicate a saturation effect, implying that additional increments in total energy intake may not yield further reduction in the likelihood of developing asthma.

Epidemiological studies show a connection between food ingredients, especially a high-calorie diet, and the onset of asthma. Antioxidant vitamins (vitamin C, vitamin E, b-carotene) and other chemicals with antioxidant potentials (phenolic acids and phytic acid in whole grains) are abundant in fruits, vegetables, dietary antioxidants, and whole grain products [1]. Fish oil is a good source of n-3 fatty acids. Prostaglandins and leukotrienes, known as eicosanoids, are examples of pro-inflammatory mediators, and they are produced mostly from n-6 and n-3 fatty acids [1, 26]. The balance will favor of n-3

Table 1 Population characteristics categorized by asthma status

Variables	Total (*n* = 21354)	Q1 (*n* = 5339)	Q2 (*n* = 5338)	Q3 (*n* = 5339)	Q4 (*n* = 5338)	*p*
Gender, n (%)						< 0.001
Females	10,349 (48.5)	2082 (39)	2412 (45.2)	2740 (51.3)	3115 (58.3)	
Age, Mean ± SD	49.2 ± 17.5	52.2 ± 17.2	51.1 ± 17.5	48.8 ± 17.4	44.6 ± 17.1	< 0.001
Race and ethnicity, n (%)						< 0.001
Mexican American	3064 (14.3)	690 (12.9)	724 (13.6)	812 (15.2)	838 (15.7)	
Other Hispanic	2119 (9.9)	528 (9.9)	554 (10.4)	530 (9.9)	507 (9.5)	
Non-Hispanic White	9034 (42.3)	2169 (40.6)	2303 (43.1)	2316 (43.4)	2246 (42.1)	
Non-Hispanic Black	4402 (20.6)	1455 (27.3)	1093 (20.5)	917 (17.2)	937 (17.6)	
Other/Multiracial	2735 (12.8)	497 (9.3)	664 (12.4)	763 (14.3)	811 (15.2)	
PIR, n (%)						< 0.001
≤1.3	6873 (32.2)	1944 (36.4)	1626 (30.5)	1501 (28.1)	1802 (33.8)	
>1.3 and ≤ 3.5	8025 (37.6)	2089 (39.1)	1981 (37.1)	2012 (37.7)	1943 (36.4)	
>3.5	6456 (30.2)	1306 (24.5)	1731 (32.4)	1825 (34.2)	1594 (29.9)	
Familial asthma, n (%)						0.002
No	16,878 (79.0)	4141 (77.6)	4227 (79.2)	4300 (80.6)	4210 (78.9)	
Yes	4476 (21.0)	1198 (22.4)	1111 (20.8)	1038 (19.4)	1129 (21.1)	
Ashma, n (%)						< 0.001
No	18,200 (85.2)	4396 (82.3)	4563 (85.5)	4637 (86.9)	4604 (86.2)	
Yes	3154 (14.8)	943 (17.7)	775 (14.5)	701 (13.1)	735 (13.8)	
Physical exercise, n (%)						< 0.001
Sedentary	10,880 (51.0)	3021 (56.6)	2834 (53.1)	2598 (48.7)	2427 (45.5)	
Moderate	5633 (26.4)	1455 (27.3)	1462 (27.4)	1409 (26.4)	1307 (24.5)	
Vigorous	4841 (22.7)	863 (16.2)	1042 (19.5)	1331 (24.9)	1605 (30.1)	
Smoking status, n (%)						< 0.001
Never	11,979 (56.1)	2975 (55.7)	3045 (57)	3063 (57.4)	2896 (54.2)	
Current	5146 (24.1)	1400 (26.2)	1374 (25.7)	1259 (23.6)	1113 (20.8)	
Former	4229 (19.8)	964 (18.1)	919 (17.2)	1016 (19)	1330 (24.9)	
BMI, Median (IQR)	28.2 (24.4, 33.0)	32.5 (27.9, 38.2)	29.4 (25.8, 33.8)	27.2 (24.1, 30.9)	25.0 (21.9, 28.4)	< 0.001
Zn, Median (IQR)	9.6 (6.6, 13.8)	6.0 (4.1, 8.6)	8.6 (6.4, 11.6)	10.5 (8.0, 14.1)	14.2 (10.7, 19.2)	< 0.001
Vitamin D, Median (IQR)	62.5 (45.4, 81.4)	58.9 (42.0, 79.0)	63.7 (46.1, 82.7)	63.7 (47.5, 82.7)	63.6 (46.5, 81.2)	< 0.001
n-3 PUFAs (mg/kg/day), Median (IQR)	1.5 (1.0, 2.4)	0.9 (0.5, 1.4)	1.4 (0.9, 2.0)	1.8 (1.2, 2.5)	2.4 (1.7, 3.5)	< 0.001
n-6 PUFAs (mg/kg/day), Median (IQR)	14.4 (9.0, 21.8)	8.1 (5.0, 12.4)	12.7 (8.8, 18.1)	16.3 (11.6, 22.4)	22.9 (16.5, 31.7)	< 0.001
Total fiber (g/day), Median (IQR)	14.7 (9.6, 21.9)	9.5 (6.1, 14.2)	13.5 (9.4, 18.8)	16.7 (11.8, 23.5)	21.1 (14.7, 29.8)	< 0.001
WBC, Median (IQR)	6.9 (5.7, 8.4)	7.1 (5.9, 8.7)	6.9 (5.7, 8.4)	6.8 (5.6, 8.2)	6.8 (5.6, 8.1)	< 0.001
Percentage of eosinophils, Median (IQR)	2.3 (1.5, 3.5)	2.3 (1.5, 3.4)	2.3 (1.5, 3.5)	2.4 (1.6, 3.7)	2.3 (1.5, 3.6)	0.021
Hemoglobin, Median (IQR)	14.0 (13.1, 15.0)	13.8 (12.7, 14.8)	14.0 (13.1, 15.0)	14.1 (13.1, 15.1)	14.3 (13.3, 15.2)	< 0.001

Abbreviations BMI body mass index; *n-3 PUFAs* n-3 polyunsaturated fatty acids; *n-6 PUFAs* n-6 polyunsaturated fatty acids; *PIR* ratio of income to poverty; *WBC* white blood cell count

Table 2 Association between dietary total energy intake (kcal/kg/day) and asthma

Variable	OR (95%CI)									
Kcal/kg/d	No.	*N* (%)	Unadjusted	*p*-value	Model 1	*p*-value	Model 2	*p*-value	Model 3	*p*-value
Q1	5339	943 (17.7)	1(Ref)		1(Ref)		1(Ref)		1(Ref)	
Q2	5338	775 (14.5)	0.79 (0.71 ~ 0.88)	< 0.001	0.83 (0.74 ~ 0.92)	0.001	0.82 (0.74 ~ 0.91)	< 0.001	0.77 (0.69 ~ 0.86)	< 0.001
Q3	5338	701 (13.1)	0.7 (0.63 ~ 0.78)	< 0.001	0.77 (0.69 ~ 0.86)	< 0.001	0.75 (0.67 ~ 0.84)	< 0.001	0.66 (0.59 ~ 0.75)	< 0.001
Q4	5339	735 (13.8)	0.74 (0.67 ~ 0.83)	< 0.001	0.77 (0.69 ~ 0.86)	< 0.001	0.76 (0.68 ~ 0.85)	< 0.001	0.61(0.53 ~ 0.69)	< 0.001
Trend. test	21,354	3154 (14.8)		< 0.001		< 0.001		< 0.001		< 0.001

Note Model 1: gender, age, race and ethnicity, familial asthma, physical exercise, smoking status and PIR; Model 2: gender, age, race and ethnicity, familial asthma, PIR, white blood cell count, percentage of eosinophils, hemoglobin count and Vitamin D; Model 3: gender, age, race and ethnicity, familial asthma, PIR, white blood cell count, percentage of eosinophils, hemoglobin count, Vitamin D, n-3 PUFAs, n-6 PUFAs, total fiber and Zn

Abbreviations CI confidence interval; *n-3 PUFAs* n-3 polyunsaturated fatty acids; *n-6 PUFAs* n-6 polyunsaturated fatty acids; *OR* odds ratio; *PIR* ratio of income to poverty; *Ref* reference; Q, quartile, Q1:<17. 73;Q2: 17.73–24.52; Q3: 21.52–33.29; Q4:>33.29

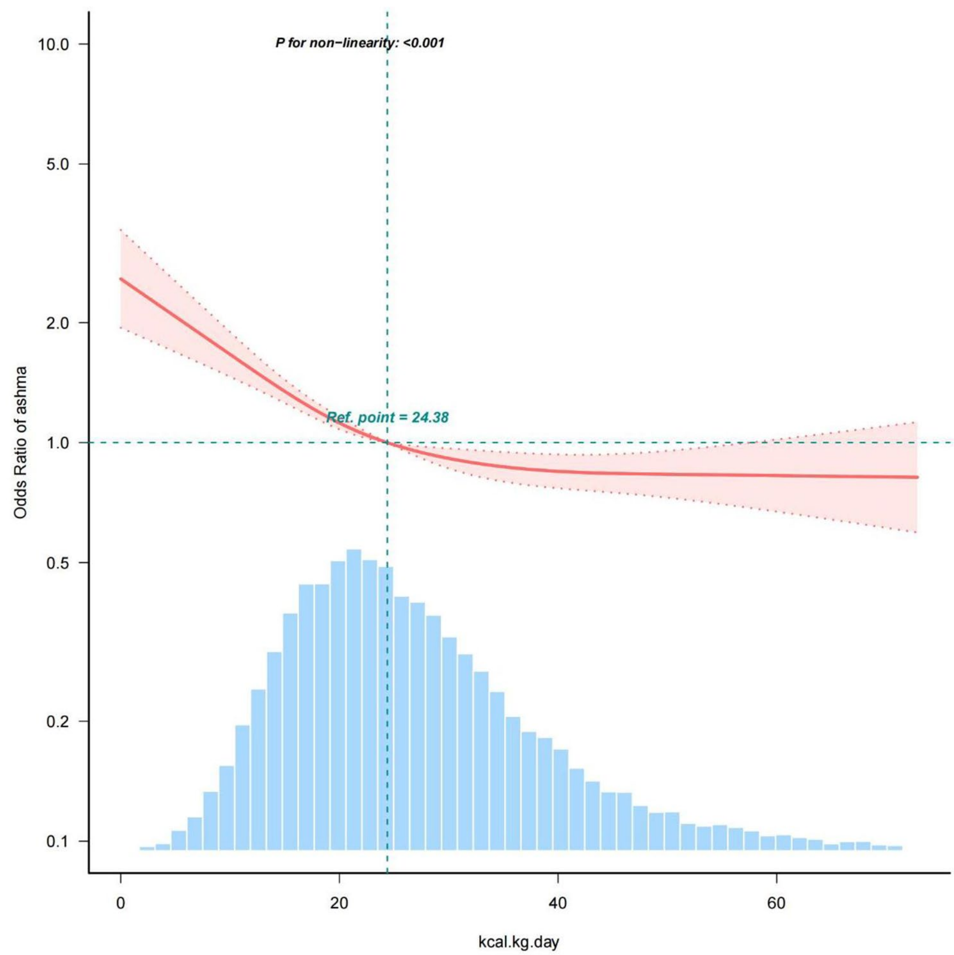

Fig. 2 Association between dietary kcal/kg intake and asthma odds ratio.Solid and dashed lines represent the predicted value and 95% confidence intervals. They were adjusted for age, sex, race and ethnicity, and PIR (ratio of income to poverty), white blood cell count, percentage of eosinophils, hemoglobin, familial asthma, physical exercise, smoking status, vitamin D, Zn, total fiber (g/day), n-3 PUFAs (mg/kg/day), n-6 PUFAs (mg/kg/day). Only 99% of the data is shown. n-3 PUFAs: n-3 polyunsaturated fatty acids, n-6 PUFAs: n-6 polyunsaturated fatty acids

Table 3 Threshold effect analysis of the relationship of total energy (kcal/kg/day) intake with asthma

Total energy(kcal/kg/day)	No.	Adjusted Model	
		OR (95% CI)	*p* value
<23.83	10,149	0.959 (0.946 ~ 0.973)	< 0.001
≥ 23.83	11,205	0.996 (0.99 ~ 1.003)	0.2477
Likelihood ratio test			< 0.001

Note Adjusted for sociodemographic age, sex, race and ethnicity, PIR, familial asthma, physical exercise, smoking status, white blood cell count, percentage of eosinophils, hemoglobin count, Vitamin D, n-3 PUFAs, n-6 PUFAs, total fiber and Zn.Only 99% of the data is displayed

Abbreviations CI confidence interval; *n-3 PUFAs* n-3 polyunsaturated fatty acids; *n-6 PUFAs* n-6 polyunsaturated fatty acids; *OR* odds ratio

fatty acid-derived eicosanoids when n-3 fatty acid intake increases, which are assumed to be biologically less active [1, 7]. The National Health and Nutrition Examination Survey (NHANES) data are the basis for this cross-sectional investigation, guaranteeing a representative sample size. Our study intends to assess the dose-response relationship and look into the relationship between dietary total energy intake and asthma among adult volunteers in the United States in order to improve our understanding of asthma management and prevention.

Although numerous studies have explored the link between diet and asthma across various life phases, including childhood [1, 27–31], prepubertal males [4], adolescents [32, 33], and adulthood [3, 34], the findings have displayed variability. According to a US study, there is a link between asthma in kids ages 2 to 9 and excessive free fructose consumption [28]. Advanced glycation end products may contribute to childhood asthma, according to the study. Based on information from the US NHANES from 2003 to 2006, children who consumed a lot of soft drinks were chosen for this study. This could introduce bias and produce results that differ from ours. Lee et al. [35]. examined the association between dietary patterns and asthma among Taiwanese schoolchildren using a multistage complex sampling design. A diet heavy in fat and simple sugars and poor in fruit, vegetables, and

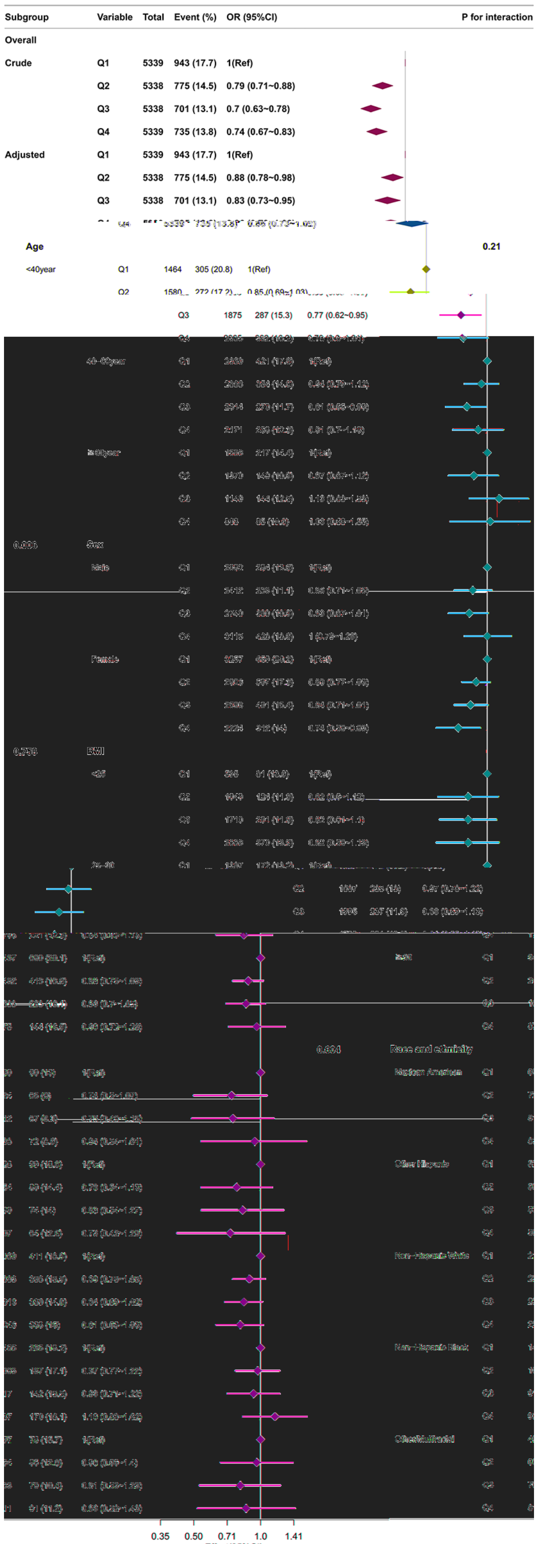

Fig. 3 Forest plot of multivariable logistics analysis between dietary total energy intake (kcal/kg/day) and asthma. Dietary total energy intake (kcal/kg/day): *Q* quartile, Q1:<17.73;Q2: 17.73–24.52; Q3: 21.52–33.29; Q4:>33.29. *CI* confidence interval; *OR* odds ratio; *PIR* ratio of income to poverty

rice is linked to a higher incidence of asthma in children from Taiwan. Nevertheless, this study is limited to only the Taiwan area since a small sample size is used to examine the relationship between diet and childhood asthma.

Systematic reviews and meta-analyses of observational studies with a focus on calorie-controlled diets for chronic asthma are available in the Cochrane database [3]. It is important to observe the conditions of adults and children with chronic asthma, dietary calorie restriction. The review is, however, constrained by the small research size and the prevalence of obesity among asthmatics. The variations in results between our study and other studies could be attributed to different populations, ages, study outcomes, and follow-up periods. In contrast to these earlier researchs, our study includes adult participants and appropriately controlled for factors that may influence asthma attacks. Finally, once total energy intake above a particular threshold, our study fails to find any significant correlation between asthma and dietary total energy consumption. However, an increase in total energy consumption within the threshold range is associated with a decline in the prevalence of asthma. It is significant to highlight that other studies somewhat corroborate our findings. For example, Maffeis et al. [4]. has found that children with mild-to-moderate asthma may benefit from using their dietary history to estimate their energy needs. Tabak et al. [1]. points out that a high-fish and whole-grain diet may prevent children from asthma. To support our argument, multicenter randomized controlled trials are still required.

Energy balance is impacted by complex physiology, including body fat distribution [36], immunological reactions [37], and dietary intake [38], which has not been completely addressed in asthmatics [39]. An increase in dietary fat, salt, and sugar consumption makes nasal hyperreactivity more apparent [40]. An further explanation for reduced food consumption in asthma patients could be related to gustatory and olfactory senses [39]. Changes in the way that one perceives olfactory or gustatory cues can have a detrimental impact on eating habits, including food preferences and the desire to eat, which can diminish the amount of different macro- and micronutrients that are consumed as well as total energy intake [7, 41–43]. In conclusion, consuming the recommended amount of total energy have a protective effect on managing and preventing asthma for adults. There aren't enough dose-response studies on the connection between adult asthma and total calorie consumption in the literature right now.

The effects of an 8-week high-intensity interval training program and/or a high-protein, low-glycaemic index dietary intervention on quality of life and asthma management in non-obese people with asthma were studied by Toennesen et al. [44]. An additional goal of the dietary intervention was to reduce inflammation; this included increasing the intake of fruits, vegetables, and seafood. The quality of life and asthma control were significantly improved in the combined intervention group as compared to the control group, but neither the exercise nor the diet groups showed any difference as compared to the control group. None of the groups showed a discernible difference in airway hyperresponsiveness or inflammation. However, the mechanisms underlying the complex relationship between a high-energy diet and an unbalanced Western diet and asthma remain unclear. The relationship between unbalanced diet intake and physical activity and the prevention of asthma deserves a series of correlation studies in the future.

Utilizing data from multiple survey cycles to attain a considerable sample size and accounting for average daily total energy intake per kilogram of body weight are key strengths of our study. There may be limitations in studying total energy intake per kilogram of body weight due to the complex link between energy intake and body mass index. We use strong techniques like threshold analysis and limited cubic splines to investigate the dose-response connection between adult asthma risk and total energy intake from diet. Our study does, however, still have certain shortcomings. It is possible for residual confounding effects to persist even using strict statistical methods. Our dietary data, laboratory data, and asthma questionnaire were all collected at the same time at the NHANES Mobile Examination Center (MEC). We recognize that the cross-sectional design of our study limited the ability to determine the directionality of the association between diet and asthma. Furthermore, a causal association between an adult's total energy consumption and asthma is prevented by the cross-sectional design. In conjunction with previous literature [10–13], the diagnosis of asthma was self-reported, and due to the limited data in the database, we were unable to analyze the type of asthma, asthma severity, and duration of the disease, and we have made a statement in the limitations section. Finally, in the NHANES database, data on spirometry were missing after 2012, so it was not possible to include spirometry as a variable. Our study was to investigate the correlation between energy intake and asthma onset, but failed to further investigate the severity of asthma and disease control, which is an area where we can conduct in-depth research in the future.

In summary, our research, which focuses on the adult population in the United States, finds an impressive L-shaped relationship between total energy consumption from food and asthma. A significant inflection point is shown by this connection at about 24 kcal/kg/day. For validation and expansion of our findings, additional large-scale prospective studies employing more precise dietary assessment methods are necessary.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
X.C., T.L., and Y.T. formulated the research, analyzed and interpreted the data, and wrote the manuscript. X.L. and L.D. designed the study, collected the data, assisted in writing the manuscript, and had primary responsibility for the final content. R.Z. reviewed the quality control data. All authors have read and approved the final manuscript.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Consent for publication
Not applicable.

Ethical approval
The participants involved in this study were reviewed and approved by National Center for Health Statistics Research Ethics Review Board. The patients/participants provided their written informed consent to participate in this study.

Registration details
This study belongs to the public database of retrospective study. Do not need to provide the registration details (registry, trial registration number, and data of registration). Public datasets used in this study are available online.

Competing interests
The authors declare no competing interests.

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