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The impact of sugar-sweetened beverages consumption on constipation: evidence from NHANES

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Abstract

Background The consumption of sugar-sweetened beverages (SSBs) has increased substantially over recent decades, raising concerns about its various physiological effects on bodily function. However, the relationship between SSBs intake and constipation remains insufficiently understood.

Methods Data from 7,979 participants sourced from the National Health and Nutrition Examination Survey (NHANES) were analyzed in this study. Dietary intake of SSBs was assessed using two 24-hour dietary recall interviews, and constipation was defined according to the Bristol Stool Form Scale (BSFS) Cards. We employed weighted logistic regression analysis to examine the relationship between SSBs consumption (quantified in grams and kilocalories) and the risk of constipation, while stratified and restricted cubic spline (RCS) analyses explored population variability.

Results After adjusting for all relevant variables, SSBs quantified in grams (SSBs-grams) (OR_{Q3} vs. $_{Q1}$ = 1.419, 95% CI: 1.064–1.893, $p=0.019$; p for trend = 0.02) and SSBs quantified in kilocalories (SSBs-kcal) (OR_{Q4} vs. $_{Q1}$ = 1.567, 95% CI: 1.100-2.234, $p=0.015$; p for trend = 0.016) showed a significant positive association with constipation. Furthermore, the weighted RCS and stratified analyses indicated that the association varied among subgroups, with a non-linear relationship between SSBs-kcal and constipation (SSBs-grams: p non-linear = 0.100, SSBs-kcal: p non-linear = 0.026).

Conclusions Our findings indicated that increased SSBs consumption is associated with a higher risk of constipation. The results underscore the need for public health interventions aimed at reducing the intake of SSBs and promoting healthier alternatives.

Keywords Sugar-sweetened beverages, Soft drinks, Constipation, NHANES

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Background

Bowel symptoms, including abdominal pain, diarrhea, constipation, bloating, and changes in bowel habits, are characterized by manifestations associated with intestines [1, 2]. Among these, constipation emerges as the most prevalent, particularly for the elderly. It is defined by three criteria: defecation frequency, stool consistency, and defecation difficulty [3, 4], with constipation specifically indicated by fewer than three bowel movements per week. Defecation frequency is influenced by a multitude of factors, including dietary habits, physical activity levels, age, and others, leading to significant individual variability. Thus, defining constipation by considering bowel movement frequency and other influencing factors is essential. Constipation is commonly characterized by stools that are lumpy, hard, dry, nutty, or granular, along with a reduced frequency of bowel movements. It is frequently accompanied by difficulties and discomfort during defecation, anal obstruction, and sometimes anal fissures with bleeding. The Global prevalence of constipation varies considerably [3, 5], with a reported 16% in North America [6], which increases with age and other factors. Constipation widespread health issue affecting physical well-being and imposing a significant economic burden on individuals and communities [7]. In the United States, chronic constipation accounts for approximately 3 million healthcare visits annually, with the associated all-cause costs reaching up to $12,000 per patient yearly. Chronic constipation is often linked to a wide range of complications [8, 9] affecting multiple organs and systems, including gastrointestinal issues like dysfunction, inflammation, obstruction, anal fissures, and hemorrhoids, as well as extra-gastrointestinal complications like obesity, cognitive disorders, myocardial and cerebral infarctions, and depression. The development of constipation is influenced by numerous factors [7, 10, 11], such as dietary factors, physical inactivity, sedentary lifestyles, advanced age, environmental influences, alcohol consumption, anxiety, depression, and medication side effects. Among these, dietary factors [12, 13] are strongly associated with constipation. Various dietary interventions have been developed to address constipation [14]. Studies have demonstrated that low-carbohydrate and low-fat diets effectively manage intestinal disorders and relieve constipation symptoms through dietary modifications. Dietary interventions for the prevention of intestinal diseases represent a direct, feasible, cost-effective, and efficient strategy for disease prevention and management via tailored dietary components.

In this study, "sugar-sweetened beverages (SSBs)" refers to any beverages sweetened with any form of sugar, including sucrose, corn sugar, corn syrup, and fruit juice concentrate, among others [15]. These include soft drinks, fruit drinks (not 100%), sports and energy drinks, nutritional beverages, smoothies, grain drinks, bottled water, carbonated water, and sweetened coffee and tea, which are major sources of dietary added sugars [16, 17]. SSBs account for approximately 24% of the added sugar intake in the United States [18]. Their consumption has imposed a substantial burden on individuals and society nationwide, posing a major global public health challenge [19, 20]. Long-term SSBs consumption adversely affects individual health and undermines the overall health of the population. Notably, the consumption of SSBs in the United States has declined over the past decade [21], partly due to regulatory measures limiting SSBs intake in various countries [22]. However, consumption has risen over the past 30 years [23], resulting in an increased burden on society. Numerous studies have established associations between SSBs and various diseases, including cardiovascular disease [24, 25] (encompassing cardiometabolic risk factors and cardiovascular disease mortality), obesity [26], metabolic syndrome [27], type 2 diabetes [28, 29], skeletal muscle disorders (e.g., gout, hyperuricemia) [30], and non-alcoholic fatty liver disease [15]. Additionally, the impact of SSBs on intestinal disorders has been extensively investigated. Evidence has demonstrated an association between SSBs consumption and inflammatory bowel disease (IBD) risk [31]. High sugar intake and SSBs consumption are linked to a higher prevalence of IBD and increased incidence of adverse cardiovascular outcomes in patients with IBD [32]. However, the potential association between SSBs and constipation remains unexplored.

In this article, we analyzed data extracted from the National Health and Nutrition Examination Survey (NHANES) to characterize individuals' constipation. The weighted multivariable logistic regression was used to investigate the association between the SSBs, quantified in grams (SSBs-grams) and kilocalories (SSBs-kcal), and the prevalence of constipation. Additionally, we also performed restricted cubic spline (RCS) and stratified analyses to further evaluate the non-linear relationships and explore the effect modification by age, gender, drinking status, and diet quality. Insights gained from this research may inform dietary guidelines and public health interventions aimed at reducing the risk of constipation.

Materials and methods

Data source

The National Health and Nutrition Examination Survey (NHANES) is a public health research program conducted by the National Center for Health Statistics (NCHS) [33]. Its main goal is to assess the health status of adults and children in the United States through periodic cross-sectional surveys that evaluate health and nutrition. NHANES releases a wide range of data biennially, including demographic, dietary, examination, laboratory, questionnaire, and limited access data. All participants in NHANES have provided informed consent, and the study protocol was approved by the NCHS Ethics Review Board (ERB) (continuation of Protocol #2005-06). As a comprehensive and representative health survey in the United States, NHANES offers extensive and reliable cross-sectional data, supporting clinical research and informing policy decisions.

Study population

We initially extracted data for 20,686 individuals from the 2007–2010 NHANES cycles. Participants were excluded based on the following criteria: (1) age < 20 years (n = 8,533); (2) self-reported colorectal cancer history (n = 104); (3) pregnancy (n = 126); (4) missing bowel health questionnaire data (n = 1,756); (5) missing SSBs intake data (n = 160); or (6) missing relevant covariates (n = 2,028). The final analyses included a total of 7,979 participants (Fig. 1).

Sugar-sweetened beverage intake

Dietary intake was measured using two 24-hour dietary recalls. The first dietary recall interview was conducted in person at the Mobile Examination Center (MEC), and the second was obtained via telephone 3–10 days later [34]. All dietary data were coded according to the United States Department of Agriculture (USDA) Food and Nutrient Database for subsequent analysis. SSBs included soft drinks, fruit drinks, sports and energy drinks, nutritional beverages, smoothies, grain drinks, bottled water, carbonated water, and sweetened coffee and tea [35, 36]. We excluded 100% fruit juice, unsweetened milk, sweetened milk, and other beverages based on the defined criteria. SSBs intake was quantified both in grams (SSBs-grams) and kilocalories (SSBs-kcal) and subsequently categorized into quartiles for analysis: quartile 1 (0.000–0.000), quartile 2 (0.000-367.200), quartile 3 (367.200-770.325), and quartile 4 (770.325-10056.69) for SSBs-grams; and quartile 1 (0–0), quartile 2 (0–74), quartile 3 (74–246), and quartile 4 (246–4124) for SSBs-kcal.

Diagnosis of constipation

According to the definition of the Bristol Stool Form Scale (BSFS), stool traits could be categorized into seven types: type 1 (separate hard lumps, like nuts), type 2 (sausage-like, but lumpy), type 3 (like a sausage but with cracks in the surface), type 4 (like a sausage or snake, smooth and soft), type 5 (soft blobs with clear-cut edges), type 6 (fluffy pieces with ragged edges, a mushy stool), and type 7 (watery, no solid pieces). Participants

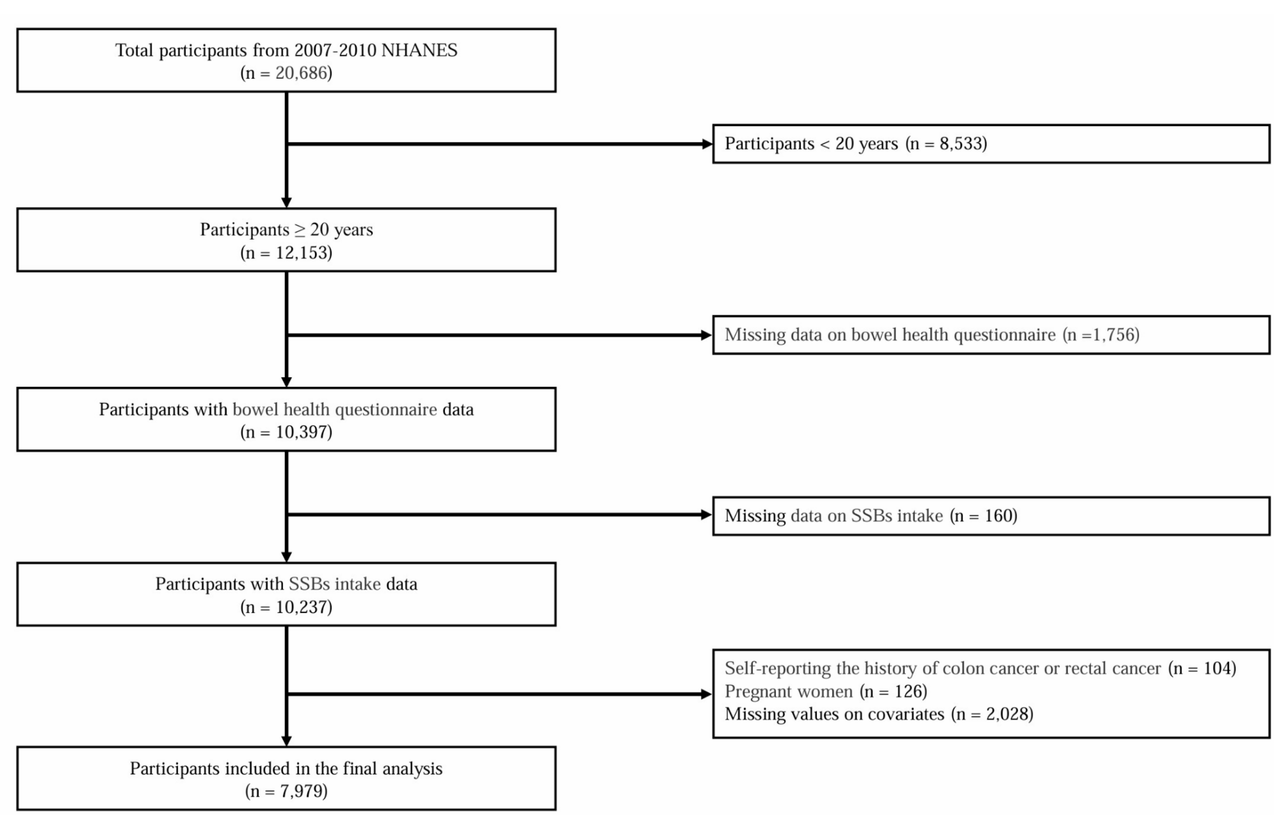


Fig. 1 Flow chart of the participants in NHANES from 2007 to 2010. Abbreviations: NHANES, the National Health and Nutrition Examination Survey; SSBs, sugar-sweetened beverages

reporting stool types 1 and 2 were defined as having constipation [37, 38].

Covariates

This study included the following covariates: age (20–39, 40–64, and ≥65 years), gender (female and male), race (non-Hispanic white, non-Hispanic black, Mexican American, and other), body mass index (BMI) (<25 kg/m^2, 25–29 kg/m^2, and ≥30 kg/m^2), poverty-income ratio (PIR) (<1, 1-1.99, 2-3.99, and ≥4), educational level (more than high school, high school, and less than high school), marital status (live together and live alone), drinking status, smoking status, dietary intake (energy, sugar, moisture, fat, and protein), physical activity levels, presence of hypertension, diabetes, depression, and the Healthy Eating Index-2015 (HEI-2015) scores (<50 and ≥50) [37]. Drinking status was categorized as yes (mild, moderate, or heavy drinkers) and no (former or never drinkers). Specifically, the categories "never", "former", "mild", "moderate", and "heavy" were defined as follows: never referred to participants who had consumed <12 drinks in a lifetime; former included participants who had consumed ≥12 drinks in a year but did not drink last year; mild pertained to participants who consumed >2 drinks per day for men or >1 drink per day for women in the past 12 months; moderate was defined by participants who consumed >3 drinks per day for men or >2 drinks per day for women in the past 12 months or 2–5 drinks overall; heavy was characterized by participants who consumed >4 drinks per day for men or >3 drinks per day for women in the past 12 months, or ≥5 drinks overall. One drink was defined as a 12-ounce of beer, a 5-ounce glass of wine, or 1.5 ounces of liquor. Smoking status was divided into now (smoked >100 cigarettes in life and currently smoked), never (smoked <100 cigarettes in life), and former (between now and never). Physical activity levels were classified as vigorous (vigorous work or recreational activities), moderate (moderate work or recreational activities), and no. Diabetes mellitus was defined as participants if they met one or more of the following criteria: (1) had been diagnosed with diabetes by a physician; (2) had an HbA1c level ≥6.5%; or (3) were on diabetes medication or insulin. Hypertension was defined as participants meeting any of the following criteria: (1) had been told by a doctor that they had hypertension or were required to take medication; (2) were currently taking antihypertensive medication; or (3) had a systolic blood pressure >140 mmHg or diastolic blood pressure >90 mmHg on more than three out of four blood pressure measurements. Depression was assessed using the Patient Health Questionnaire-9 (PHQ-9), with scores categorized as none (≤4), mild (5–9), moderate (10–14), moderately-severe (15–19), and severe (≥20) [39, 40].

Statistical analysis

Analyses were performed using R version 4.3.2 (2023-10-31, https://www.r-project.org/). To enhance analytical rigor, we extracted and applied relevant dietary weights to all data. Processing of all weighted data followed the NHANES Analytic and Reporting Guidelines (https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx#analytic-guidelines). Continuous variables were presented as weighted means (standard error) (S.E) and compared between groups using weighted Student's t-tests. Categorical variables were presented as numbers (n) and survey-weighted percentages, with group comparisons using weighted chi-square tests.

We used weighted multivariable logistic regression to explore the association between SSBs and constipation, developing four models: the crude model was not adjusted for any variables; model 1 was adjusted for age, gender, and race; model 2 was adjusted for age, gender, race, PIR, BMI, educational level, marital status, drinking status, smoking status, energy, sugar, moisture, fat, protein, physical activity levels, hypertension, diabetes, and depression; model 3 was further adjusted for HEI-2015 scores based on model 2, with age, PIR, BMI, and HEI-2015 scores treated as categorical variables. Weighted restricted cubic spline (RCS) analyses were conducted to examine potential non-linear relationships to further evaluate the non-linear relationships between SSBs intake and constipation risk. Furthermore, stratified analyses were performed to assess whether associations varied by age, gender, drinking status, and diet quality. A two-sided p-value <0.05 was considered statistically significant.

Results

Basic characteristics of participants

Among the 7,979 participants included in the final analysis, 618 (7.74%) were identified as having constipation. As summarized in Table 1, individuals with constipation were significantly younger (44.64 ± 0.92 vs. 46.99 ± 0.38, $p=0.01$), more likely to be aged 20–39 years (42.80% vs. 36.16%, $p=0.03$), female (68.18% vs. 50.49%, $p<0.0001$), and Non-Hispanic Black (14.94% vs. 10.22%, $p=0.02$) compared to those without constipation. Moreover, participants with constipation exhibited lower educational levels, a lower PIR (2.78 ± 0.11 vs. 3.07 ± 0.06, $p=0.01$), and a lower BMI (27.42 ± 0.39 vs. 28.95 ± 0.12, $p<0.001$). Additionally, they reported less alcohol consumption (33.64% vs. 26.22%, $p=0.01$), poorer diet quality (HEI-2015 scores: 50.87 ± 0.79 vs. 53.75 ± 0.40, $p<0.001$), lower levels of physical activity, and a higher prevalence of depression (PHQ-9 scores: 4.24 ± 0.28 vs. 3.04 ± 0.10, $p<0.001$). Notably, both SSBs-kcal (211.96 ± 16.09 vs. 162.49 ± 8.62, $p<0.001$) and SSBs-grams (690.43 ± 46.37

Table 1 Basic characteristics of participants

Characteristic	No	Yes	*P* value
Age (years), mean (S.E)	46.99(0.38)	44.64(0.92)	0.01
Age (years), n (%)			0.03
20–39	2286(36.16)	222(42.80)	
40–64	3229(47.33)	260(42.23)	
≥ 65	1846(16.51)	136(14.97)	
Gender, n (%)			< 0.0001
Female	3651(50.49)	424(68.18)	
Male	3710(49.51)	194(31.82)	
Race, n (%)			0.02
Non-Hispanic White	3838(72.34)	287(64.88)	
Non-Hispanic Black	1334(10.22)	136(14.94)	
Mexican American	1212(7.78)	93(8.68)	
Other	977(9.67)	102(11.50)	
Educational level, n (%)			< 0.0001
More than high school	3707(59.43)	244(45.24)	
High school	1732(23.22)	174(30.52)	
Less than high school	1922(17.35)	200(24.24)	
Marital status, n (%)			0.17
Live together	4544(63.60)	346(59.12)	
Live alone	2817(36.40)	272(40.88)	
PIR, mean (S.E)	3.07(0.06)	2.78(0.11)	0.01
PIR, n (%)			0.01
< 1	1438(13.57)	154(19.12)	
1-1.99	1977(19.80)	169(21.90)	
2-3.99	1961(27.82)	167(26.43)	
≥ 4	1985(38.81)	128(32.56)	
BMI (kg/m^2), mean (S.E)	28.95(0.12)	27.42(0.39)	< 0.001
BMI (kg/m^2), n (%)			< 0.001
< 25	1973(29.75)	222(40.02)	
25–29	2534(33.33)	199(34.32)	
≥ 30	2854(36.91)	197(25.66)	
HEI-2015 scores, mean (S.E)	53.75(0.40)	50.87(0.79)	< 0.001
HEI-2015 scores, n (%)			0.004
< 50	2962(41.33)	282(49.55)	
≥ 50	4399(58.67)	336(50.45)	
Physical activity levels, n (%)			< 0.001
Moderate	2938(46.10)	211(40.72)	
Vigorous	1200(16.95)	85(12.22)	
No	3223(36.94)	322(47.06)	
Drinking status, n (%)			0.01
No	2367(26.22)	242(33.64)	
Yes	4994(73.78)	376(66.36)	
Smoking status, n (%)			0.15
Now	1577(20.89)	129(21.86)	
Former	1936(25.29)	124(20.31)	
Never	3848(53.82)	365(57.83)	
Hypertension, n (%)			0.23
No	4183(64.40)	378(67.45)	
Yes	3178(35.60)	240(32.55)	
Diabetes, n (%)			0.06
No	6200(88.98)	524(91.80)	
Yes	1161(11.02)	94(8.20)	
PHQ-9 scores, mean (S.E)	3.04(0.10)	4.24(0.28)	< 0.001

Table 1 (continued)

Characteristic	No	Yes	*P* value
Depression, **n (%)**			< 0.0001
None	5581(77.03)	408(63.93)	
Mild	1121(15.36)	125(21.01)	
Moderate	407(4.99)	53(10.65)	
Moderately-Severe	183(1.97)	25(3.74)	
Severe	69(0.66)	7(0.67)	
SSBs-kcal, **mean (S.E)**	162.49(8.62)	211.96(16.09)	< 0.001
SSBs-grams, **mean (S.E)**	586.48(28.44)	690.43(46.37)	0.02

Abbreviations: n (%), number (weighted percentage); S.E, standard error; PIR, the poverty-income ratio; BMI, body mass index; SSBs, sugar-sweetened beverages; HEI-2015, Healthy Eating Index-2015; PHQ-9, Patient Health Questionnaire-9

Table 2 Relationship between SSBs and constipation

	crude model	*P* value	Model 1	*P* value	Model 2	*P* value	Model 3	*P* value
SSBs-grams ORs (95%CIs)								
Quartile 1	ref		ref		ref		ref	
Quartile 2	1.109(0.812,1.516)	0.503	1.056(0.763,1.463)	0.731	0.996(0.722,1.374)	0.98	0.979(0.707,1.357)	0.898
Quartile 3	1.485(1.102,2.002)	0.011	1.565(1.159,2.115)	0.005	1.484(1.114,1.977)	0.009	1.419(1.064,1.893)	0.019
Quartile 4	1.465(1.144,1.875)	0.004	1.571(1.216,2.029)	0.001	1.538(1.083,2.184)	0.018	1.439(0.996,2.078)	0.052
P for trend		0.001		< 0.001		0.207		0.02
SSBs-kcal ORs (95%CIs)								
Quartile 1	ref		ref		ref		ref	
Quartile 2	1.035(0.728,1.470)	0.844	1.049(0.738,1.491)	0.78	1.121(0.786,1.598)	0.517	1.103(0.772,1.576)	0.581
Quartile 3	1.390(1.039,1.860)	0.028	1.425(1.057,1.922)	0.022	1.341(0.978,1.839)	0.067	1.280(0.936,1.751)	0.117
Quartile 4	1.684(1.301,2.181)	< 0.001	1.833(1.382,2.430)	< 0.001	1.691(1.214,2.355)	0.003	1.567(1.100,2.234)	0.015
P for trend		< 0.001		< 0.001		0.196		0.016

The crude model was not adjusted for any variables. Model 1 was adjusted for age, gender, and race. Model 2 was adjusted for age, gender, race, PIR, BMI, educational level, marital status, drinking status, smoking status, energy, sugar, moisture, fat, protein, physical activity levels, hypertension, diabetes, and depression. Model 3 was further adjusted for HEI-2015 scores based on Model 2. Abbreviations: ORs, odds ratios, CIs, confidence intervals; SSBs, sugar-sweetened beverages; PIR, the poverty-income ratio; BMI, body mass index; HEI-2015, Healthy Eating Index-2015

vs. 586.48 ± 28.44, $p = 0.02$) were significantly higher among participants with constipation.

Association between SSBs and constipation

Weighted multivariable logistic regression analysis revealed a positive association between SSB consumption and constipation. In model 1, which was not adjusted for any variables, Table 2 indicated that both SSBs-grams ($OR_{Q3\ vs.\ Q1}$ = 1.485, 95% CI: 1.102–2.002, $p = 0.011$; $OR_{Q4\ vs.\ Q1}$ = 1.465, 95% CI: 1.144–1.875, $p = 0.004$; p for trend = 0.001) and SSBs-kcal ($OR_{Q3\ vs.\ Q1}$ = 1.390, 95% CI: 1.039–1.860, $p = 0.028$; $OR_{Q4\ vs.\ Q1}$ = 1.684, 95% CI: 1.301–2.181, $p < 0.001$; p for trend < 0.0001) were significantly associated with constipation. The association remained statistically significant in model 3 between SSBs-grams ($OR_{Q3\ vs.\ Q1}$ = 1.419, 95% CI: 1.064–1.893, $p = 0.019$; p for trend = 0.02) and SSBs-kcal ($OR_{Q4\ vs.\ Q1}$ = 1.567, 95% CI: 1.100-2.234, $p = 0.015$; p for trend = 0.016) and the prevalence of constipation. Further analysis of specific beverage types, as shown in Supplementary Table 1, indicated that the SSBs-grams from soft drinks ($OR_{Q2\ vs.\ Q1}$ = 1.681, 95% CI: 1.109–2.548, $p = 0.016$) and smoothies and carbonated water ($OR_{Q2\ vs.\ Q1}$ = 1014.973, 95% CI: 2.106-489106.849, $p = 0.020$) were strongly associated with constipation.

RCS analyses were conducted to further simulate the potential non-linear relationship between SSBs and constipation. As shown in Fig. 2, there was no evidence of a non-linear relationship between SSBs-grams and constipation (p overall: 0.008, p non-linear: 0.100), whereas SSBs-kcal revealed a significant non-linear trend (p overall: 0.010, p non-linear: 0.026). The trend analysis substantiated the regression results presented in Table 2, indicating that higher SSBs consumption is associated with an increased risk of constipation.

Subgroup analysis

To investigate whether stratified variables modified the observed association between SSBs and constipation, we conducted weighted stratified and interaction analyses based on age, gender, drinking status, and HEI-2015 scores. As shown in Fig. 3, the SSBs-grams in participants aged 20–39 years ($OR_{Q3\ vs.\ Q1}$ = 2.267, 95% CI: 1.386–3.708, $p = 0.002$; $OR_{Q4\ vs.\ Q1}$ = 2.171, 95% CI:

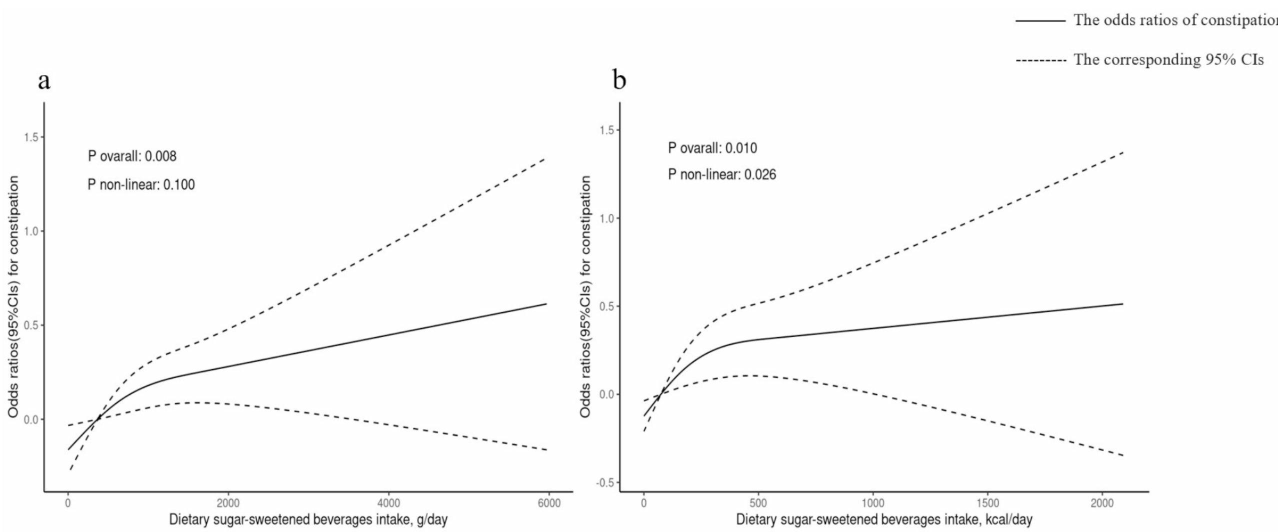


Fig. 2 Association between SSBs-grams (**a**) as well as SSBs-kcal (**b**) and constipation. RCS analysis was conducted in model 3 which was adjusted for all covariates. The ORs of constipation were shown as solid black lines, and the corresponding 95% CIs were shown as short black dashed lines. Abbreviations: ORs, odds ratios; CIs, confidence intervals; SSBs, sugar-sweetened beverages

1.099–4.288, $p = 0.027$) and SSBs-kcal ($OR_{Q3\ vs.\ Q1}$ = 1.735, 95% CI: 1.018–2.955, $p = 0.043$; $OR_{Q4\ vs.\ Q1}$ = 2.119, 95% CI: 1.142–3.933, $p = 0.01$) exhibited significant positive associations with constipation. Among females, SSBs-kcal ($OR_{Q4\ vs.\ Q1}$ = 1.585, 95% CI: 1.006–2.497, $p = 0.047$) was positively associated with constipation. Similarly, participants who consumed alcohol exhibited a positive association between constipation and both SSBs-grams ($OR_{Q3vs.\ Q1}$ = 1.725, 95% CI: 1.156–2.573, $p = 0.009$) and SSBs-kcal ($OR_{Q4\ vs.\ Q1}$ = 1.727, 95% CI: 1.074–2.777, $p = 0.026$). When stratified by diet quality, Fig. 3 revealed that participants with high diet quality (HEI-2015 scores ≥ 50) exhibited a significant association between SSBs-grams ($OR_{Q4\ vs.\ Q1}$ = 1.705, 95% CI: 1.009–2.881, $p = 0.047$) and constipation prevalence. However, the observed differences were not statistically significant (all p for interaction > 0.05).

Sensitivity analysis

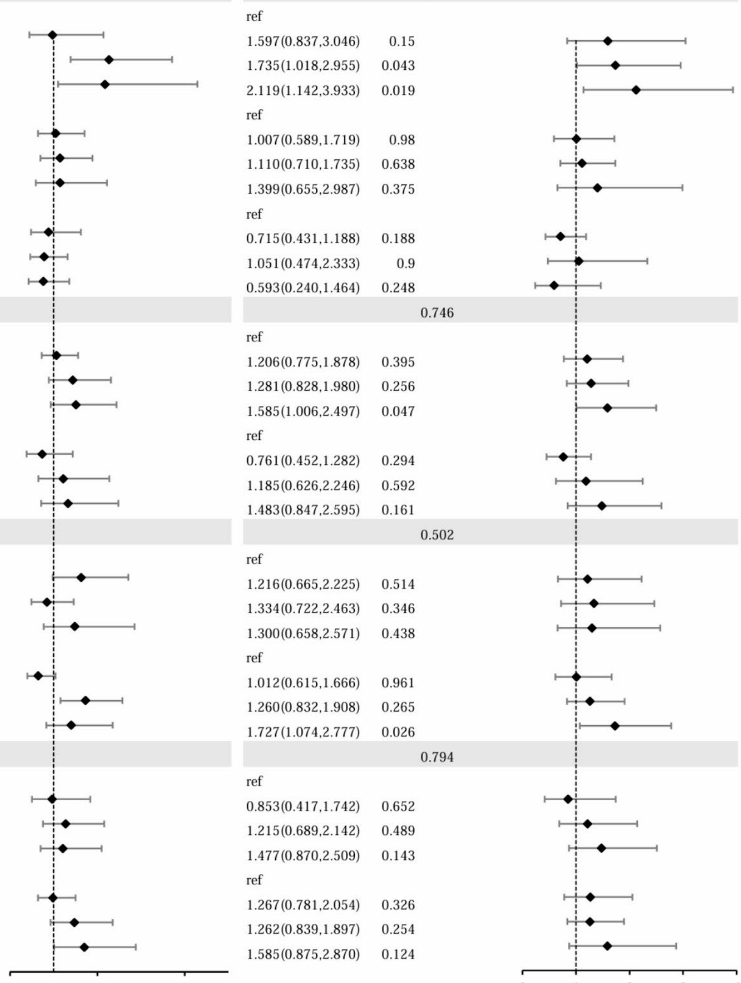
To assess the robustness of our findings, we subsequently conducted a sensitivity analysis. Extreme SSBs intakes were defined as those within the top 1% of the SSBs intake distribution. We then performed the weighted multivariable logistic regression analysis on the data after excluding the extreme values. Table 3 revealed a positive association between SSBs-grams ($OR_{Q3\ vs.\ Q1}$ = 1.415, 95% CI: 1.057–1.895, $p = 0.021$; p for trend = 0.032) as well as SSBs-kcal ($OR_{Q4\ vs.\ Q1}$ = 1.457, 95% CI: 1.003–2.115, $p = 0.048$; p for trend = 0.036) and constipation. These findings demonstrated a high degree of concordance with the regression results in Table 2, indicating that the results were not influenced by these extreme values and were highly reliable and robust.

Discussion

This study provided critical insights into the association between SSBs and constipation. Our findings indicated that higher SSBs intake-whether measured in grams or kilocalories-was significantly associated with an increased prevalence of constipation.

Participants in the higher quartiles of SSBs consumption had elevated odds of constipation even after adjusting for all covariates. Additionally, weighted RCS analyses further indicated that there was a non-linear relationship between SSBs-kcal and constipation. Weighted stratified analyses revealed that the association was particularly pronounced among younger adults (aged 20–39 years), females, and individuals who consumed alcohol and with higher HEI-2015 scores.

Constipation represents a prevalent gastrointestinal symptom and a widespread health problem in our country [41], with higher incidence rates among the elderly and females [42]. The prevalence of constipation varies widely, ranging from 0.7 to 79% in North America, highlighting its substantial global impact [8, 9]. After applying the nadir criteria, 618 of 7,979 participants (7.74%) were identified as having constipation. Constipation is linked to a variety of complications [43], underscoring the critical need for effective prevention and treatment. SSBs, defined as beverages sweetened with added sugar or other sweeteners [44], are typically high in sugar and kilocalories but lack nutritional value. Evidence suggests [16] that the consumption of SSBs is increasing among children (from 87 kcal/day to 154 kcal/day) and adults. SSBs contribute to a significant global, regional, and national disease burden, with variations by age and gender groups [20]. A cross-sectional study [31] involving 121,490



Character	SSBs Quartile	SSBs-grams ORs (95%CIs)	P value	p for interaction	SSBs-kcal ORs (95%CIs)	P value	p for interaction
Age, n (%)				0.206			0.424
20-39	Quartile 1	ref			ref		
	Quartile 2	0.976(0.445,2.139)	0.95		1.597(0.837,3.046)	0.15	
	Quartile 3	2.267(1.386,3.708)	0.002		1.735(1.018,2.955)	0.043	
	Quartile 4	2.171(1.099,4.288)	0.027		2.119(1.142,3.933)	0.019	
40-64	Quartile 1	ref			ref		
	Quartile 2	1.046(0.642,1.705)	0.853		1.007(0.589,1.719)	0.98	
	Quartile 3	1.144(0.694,1.886)	0.588		1.110(0.710,1.735)	0.638	
	Quartile 4	1.147(0.592,2.220)	0.676		1.399(0.655,2.987)	0.375	
≥ 65	Quartile 1	ref			ref		
	Quartile 2	0.881(0.479,1.621)	0.675		0.715(0.431,1.188)	0.188	
	Quartile 3	0.781(0.462,1.318)	0.343		1.051(0.474,2.333)	0.9	
	Quartile 4	0.759(0.425,1.357)	0.341		0.593(0.240,1.464)	0.248	
Gender, n (%)				0.89			0.746
Female	Quartile 1	ref			ref		
	Quartile 2	1.062(0.724,1.558)	0.75		1.206(0.775,1.878)	0.395	
	Quartile 3	1.433(0.887,2.313)	0.136		1.281(0.828,1.980)	0.256	
	Quartile 4	1.507(0.932,2.437)	0.092		1.585(1.006,2.497)	0.047	
Male	Quartile 1	ref			ref		
	Quartile 2	0.739(0.381,1.435)	0.36		0.761(0.452,1.282)	0.294	
	Quartile 3	1.215(0.649,2.272)	0.532		1.185(0.626,2.246)	0.592	
	Quartile 4	1.330(0.712,2.481)	0.359		1.483(0.847,2.595)	0.161	
Drinking status, n (%)				0.003			0.502
No	Quartile 1	ref			ref		
	Quartile 2	1.628(0.978,2.709)	0.06		1.216(0.665,2.225)	0.514	
	Quartile 3	0.845(0.490,1.456)	0.533		1.334(0.722,2.463)	0.346	
	Quartile 4	1.484(0.772,2.852)	0.228		1.300(0.658,2.571)	0.438	
Yes	Quartile 1	ref			ref		
	Quartile 2	0.643(0.397,1.041)	0.071		1.012(0.615,1.666)	0.961	
	Quartile 3	1.725(1.156,2.573)	0.009		1.260(0.832,1.908)	0.265	
	Quartile 4	1.397(0.830,2.349)	0.2		1.727(1.074,2.777)	0.026	
HEI-2015 scores, n (%)				0.848			0.794
< 50	Quartile 1	ref			ref		
	Quartile 2	0.959(0.501,1.835)	0.896		0.853(0.417,1.742)	0.652	
	Quartile 3	1.276(0.756,2.155)	0.35		1.215(0.689,2.142)	0.489	
	Quartile 4	1.211(0.700,2.095)	0.482		1.477(0.870,2.509)	0.143	
≥ 50	Quartile 1	ref			ref		
	Quartile 2	0.982(0.642,1.500)	0.93		1.267(0.781,2.054)	0.326	
	Quartile 3	1.477(0.928,2.351)	0.097		1.262(0.839,1.897)	0.254	
	Quartile 4	1.705(1.009,2.881)	0.047		1.585(0.875,2.870)	0.124	

Fig. 3 The weighted stratified and interaction analyses of the relationship between SSBs and constipation. The weighted stratified and interaction analyses of the relationship between SSBs-grams (shown in the left half of the figure), as well as SSBs-kcal (shown in the right half of the figure) and constipation, were conducted in model 3 by removing the applied categorical variables at the time of their respective strata. Abbreviations: ORs, odds ratios; CIs, confidence intervals; SSBs, sugar-sweetened beverages; HEI-2015, Healthy Eating Index-2015

participants identified an increased inflammatory bowel disease risk with SSB consumption, particularly Crohn's disease. While the association between SSBs and the gastrointestinal tract has been investigated, the association with constipation remains less well-defined. In this study, as shown in Table 1, participants with constipation had significantly higher mean SSBs-kcal (211.96 ± 16.09 vs. 162.49 ± 8.62, $p < 0.001$) and SSBs-grams (690.43 ± 46.37 vs. 586.48 ± 28.44, $p = 0.02$) than those without constipation. Similar conclusions could be drawn from the weighted multivariable logistic regression analysis presented in Table 2, SSBs-grams ($OR_{Q3\text{ vs. }Q1}$ = 1.419, 95% CI: 1.064–1.893, $p = 0.019$; p for trend = 0.02) and SSBs-kcal ($OR_{Q4\text{ vs. }Q1}$ = 1.567, 95% CI: 1.100-2.234, $p = 0.015$; p for trend = 0.016) exhibited a significant positive association with constipation after adjusting for all variables. Supplementary Table 1 indicated a notable link between soft drinks ($OR_{Q2\text{ vs. }Q1}$ = 1.681, 95% CI: 1.109–2.548, $p = 0.016$) and constipation. As the most widely consumed beverage [45], excessive soft drink consumption can lead to various health complications, including obesity [46], diabetes [47], dental disease, and intestinal health problems. Research has shown a positive association between increased consumption of soft drinks and constipation in Indonesian adolescents [48]. Moreover, the ingestion of coffee and tea may exert a detrimental effect on the digestive system, potentially increasing constipation risk [49].

Constipation prevalence varies by age and gender. As shown in Table 1, constipation was more prevalent

Table 3 The sensitivity analysis by excluding participants with extreme SSBs intake

	crude model	*P* value	Model 1	*P* value	Model 2	*P* value	Model 3	*P* value
SSBs-grams ORs (95%CIs)								
Quartile 1	ref		ref		ref		ref	
Quartile 2	1.121(0.811,1.549)	0.477	1.066(0.761,1.493)	0.699	1.003(0.719,1.399)	0.987	0.987(0.704,1.382)	0.936
Quartile 3	1.491(1.102,2.016)	0.011	1.560(1.150,2.116)	0.006	1.477(1.103,1.977)	0.01	1.415(1.057,1.895)	0.021
Quartile 4	1.437(1.098,1.879)	0.01	1.531(1.166,2.012)	0.004	1.484(1.038,2.121)	0.032	1.394(0.960,2.024)	0.079
P for trend		0.003		< 0.001		0.225		0.032
SSBs-kcal ORs (95%CIs)								
Quartile 1	ref		ref		ref		ref	
Quartile 2	0.975(0.678,1.402)	0.888	0.994(0.692,1.427)	0.972	1.091(0.750,1.586)	0.64	1.073(0.736,1.564)	0.707
Quartile 3	1.485(1.083,2.034)	0.016	1.509(1.092,2.085)	0.015	1.388(1.001,1.924)	0.049	1.334(0.966,1.841)	0.079
Quartile 4	1.621(1.234,2.128)	0.001	1.743(1.297,2.341)	< 0.001	1.572(1.107,2.234)	0.013	1.457(1.003,2.115)	0.048
P for trend		< 0.001		< 0.001		0.227		0.036

The crude model was not adjusted for any variables. Model 1 was adjusted for age, gender, and race. Model 2 was adjusted for age, gender, race, PIR, BMI, educational level, marital status, drinking status, smoking status, energy, sugar, moisture, fat, protein, physical activity levels, hypertension, diabetes, and depression. Model 3 was further adjusted for HEI-2015 scores based on Model 2. Abbreviations: ORs, odds ratios, CIs, confidence intervals; SSBs, sugar-sweetened beverages; PIR, the poverty-income ratio; BMI, body mass index; HEI-2015, Healthy Eating Index-2015

among younger women. However, epidemiological evidence suggests that constipation is significantly more common in older adults [42], possibly due to comorbidities. Additionally, alcohol consumption was identified as a risk factor for constipation, with diet quality differences affecting gut health and modulating SSBs' impact. To further identify high-risk populations, we conducted a weighted stratified analysis using age, gender, alcohol consumption, and diet quality as stratification factors. The results presented in Fig. 3 demonstrated that the risk of constipation may rise with increased SSBs-grams and SSBs-kcal in participants aged 20–39 years. This conclusion could also be drawn from Table 1, which indicated a higher prevalence of constipation in this age group (42.80% vs. 36.16%, $p = 0.03$). Consistent with a 2010 study [16], the consumption of SSBs typically declined with age, implying that the requirements of SSBs may fluctuate across different life stages. Moreover, constipation prevalence differed between female and male participants (68.18% vs. 50.49%, $p < 0.0001$), likely attributed to the inherent physiological and lifestyle differences [50]. Stratified by drinking status, the study found that there was a closer link between intake of SSBs and constipation among alcohol consumers. This is likely because alcohol consumption itself is a risk factor for constipation, inhibiting peristalsis and decelerating intestinal transit. Alcohol also exerted a modulating effect on the intestinal microbiota [51], potentially increasing intestinal issues like constipation, aligning with our findings. Previous studies had demonstrated a positive association between SSBs and constipation in the group with higher HEI-2015 scores. However, one study reported a negative association [37], with high-diet-quality participants (high HEI-2015 scores) having lower constipation prevalence than those with low diet quality. The present study's inconsistent results with prior research may be a consequence of a complex interplay of factors, potentially including the participants' simultaneous pursuit of a high dietary quality and high SSBs intake. It is plausible that the SSBs components may affect the absorption and utilization of nutrients or alter the intestinal microbiota, ultimately triggering constipation. Alternatively, some covariates, such as insufficient physical activity, depression, or other physical illnesses may further exacerbate the risk of constipation. Consequently, further research is required to verify the reliability of the subgroup analysis results and the relationship between these factors and constipation.

Our findings suggest a significant association between the consumption of SSBs and constipation. The underlying mechanisms may be related to the following aspects. A study published in 2019 demonstrated that dysfunction in intestinal motility was a contributing factor to constipation [7]. SSBs can affect intestinal motility time [52] by altering intestinal physiology, resulting in a deceleration of intestinal peristalsis. This may be due to the sugars in SSBs impacting the enteric nervous system, potentially through changes in neurotransmitter release and receptor binding, consequently influencing intestinal function. Abnormal gut microbiota [53, 54] can also cause constipation. Several studies have shown that the high sugar in SSBs negatively affects the gut microbiota [52, 55], increasing harmful bacteria, inhibiting beneficial bacteria, and altering the intestinal flora composition in mice. Such imbalances disrupt peristalsis and gut barrier function, allowing the infiltration of harmful substances into the intestines and raising the risk of constipation. Additionally, physiological changes from elevated SSBs intake [56], such as blood glucose fluctuations, may impair intestinal function and have detrimental effects on the intestinal tract. These fluctuations can cause insulin resistance and other physiological responses, thereby increasing the risk of constipation. Notably, some covariates included in this study have also been shown to be associated with constipation. High intake of SSBs is associated with an increased risk of depression [40], malnutrition [57], diabetes [19, 58], and obesity, which are also interconnected with constipation. Nevertheless, the precise mechanisms remain unclear and require further investigation to ascertain the potential mechanisms and causal relationship. In summary, reducing SSBs intake to lower the risk of constipation is crucial for public health. Previous epidemiology emphasizes the global public health impact of increased SSBs intake. Reducing SSBs not only cuts the risk of constipation and other bowel diseases but also significantly benefits adolescent and child health, mental health, and global health, easing the burden on the healthcare system. It could also prompt the food industry to change the type of beverages marketed, produce healthier and tastier beverages, and boost productivity. In the future, it will be necessary to develop policies like existing tax policies and advertising restrictions, and a comprehensive implementation strategy for multi-structural societal cooperation in health education and promotion to maximize public health benefits.

This study had several key advantages. First of all, the use of a large, nationally representative sample included 7,979 participants from the 2007–2010 NHANES database, and the application of a rigorous multi-stage probability sampling method effectively represented the U.S. population and ensured broad representativeness. Notably, this study was the first investigation into the association between SSBs and constipation. In addition to delineating the general characteristics of constipation, we also adjusted for a comprehensive set of potential confounders, enhancing the accuracy and reliability of the findings. However, some limitations should be acknowledged. The cross-sectional design limited our ability to establish causality between SSBs and constipation, necessitating the execution of cohort studies or randomized controlled trials. SSBs consumption data from two 24-hour dietary recalls may inevitably introduce reporting or recall bias, potentially affecting the data accuracy and reliability. Future studies could use more objective and accurate dietary assessment methods, such as real-time dietary tracking via smart devices or dietary biomarkers. We quantified SSBs intake in grams and kilocalories but did not account for individual bioavailability variability. Finally, the inevitable challenge of over-stratification and reduced statistical power emerged in the subgroup analyses. Subsequent analyses should include measures to mitigate the effects of these problems, such as limiting the number of strata, increasing the sample size, or conducting sensitivity analyses. Finally, despite our comprehensive efforts to incorporate a wide range of potential confounders, it is recognized that the other relevant confounders may have been missed. In conclusion, our findings offer novel insights into the SSBs-constipation relationship, underscoring its influence on public health. Future longitudinal studies are needed to confirm these associations and elucidate the underlying mechanisms linking SSBs to gastrointestinal dysfunction.

Conclusions

The study demonstrated a robust positive association between SSBs consumption and the prevalence of constipation, with RCS and stratified analyses showing the non-linear relationship and variations across populations. Given the detrimental health effects of SSBs, it is crucial to formulate and implement policies aimed at reducing their consumption, alongside promoting the identification and adoption of healthier alternatives.

Abbreviations

SSBs	Sugar-sweetened beverages
NHANES	National Health and Nutrition Examination Survey
BSFS	Bristol Stool Form Scale
RCS	Restricted cubic spline
IBD	Inflammatory bowel disease
NCHS	National Center for Health Statistics
USDA	United States Department of Agriculture
MEC	Mobile Examination Center
BMI	Body mass index
PIR	Poverty-income ratio
HEI-2015	Healthy Eating Index-2015 scores
PHQ-9	Patient Health Questionnaire-9

Supplementary Information

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Supplementary Material 1

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Author contributions

X.Z., M.L., Y.Z., Y.W., and Y.Z. were responsible for the work described in this article. X.Z., Y.Z., and Y.W. were responsible for the literature search and determination of the research direction. X.Z., M.L., and Z.Y. were responsible for downloading the data and conducting the requisite analysis. X.Z., Y.W., and Y.Z. were responsible for interpreting the data. X.Z. and Z.Y. were responsible for drafting the manuscript. Y.Z., M.L., Y.W., and Y.Z. were responsible for checking and revising the key points of the manuscript. All authors read and approved the final manuscript.

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Data availability

Data are publicly available online (https://wwwn.cdc.gov/nchs/nhanes).

Declarations

Ethics approval and consent to participate

This study did not entail any risk to human subjects, which was performed following the Declaration of Helsinki and approved by the NCHS Research Ethics Review Board (https://www.cdc.gov/nchs/nhanes/irba98.htm; accessed on August 24, 2022). NHANES was approved by the National Centre for Health Statistics research ethics review board. All participants in NHANES have provided informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Choung RS, Locke GR 3rd, Schleck CD, Zinsmeister AR, Talley NJ. Cumulative incidence of chronic constipation: a population-based study 1988–2003. Aliment Pharmacol Ther. 2007;26(11–12):1521–8.
2. Andy UU, Vaughan CP, Burgio KL, Alli FM, Goode PS, Markland AD. Shared risk factors for constipation, fecal incontinence, and combined symptoms in older U.S. Adults. J Am Geriatr Soc. 2016;64(11):e183–8.
3. Schiller LR. Chronic constipation: new insights, better outcomes? Lancet Gastroenterol Hepatol. 2019;4(11):873–82.
4. Bharucha AE, Lacy BE. Mechanisms, evaluation, and management of chronic constipation. Gastroenterology. 2020;158(5):1232–e12491233.
5. Barberio B, Judge C, Savarino EV, Ford AC. Global prevalence of functional constipation according to the Rome criteria: a systematic review and meta-analysis. Lancet Gastroenterol Hepatol. 2021;6(8):638–48.
6. Bharucha AE, Pemberton JH, Locke GR 3. American gastroenterological association technical review on constipation. Gastroenterology. 2013;144(1):218–38.
7. Bharucha AE, Wald A. Chronic Constipation. Mayo Clin Proc. 2019;94(11):2340–2357.
8. Leta V, Urso D, Batzu L, Weintraub D, Titova N, Aarsland D, Martinez-Martin P, Borghammer P, van Wamelen DJ, Yousaf T, Rizos A, Rodriguez-Blazquez C, Chung-Faye G, Chaudhuri KR. Constipation is associated with development of cognitive impairment in de Novo Parkinson's disease: A longitudinal analysis of two international cohorts. J Parkinsons Dis. 2021;11(3):1209–19.
9. Kawamura Y, Yamamoto S, Funaki Y, Ohashi W, Yamamoto K, Ozeki T, Yamaguchi Y, Tamura Y, Izawa S, Hijikata Y, Ebi M, Ogasawara N, Sasaki M, Kasugai K. Internet survey on the actual situation of constipation in the Japanese population under 70 years old: focus on functional constipation and constipation-predominant irritable bowel syndrome. J Gastroenterol. 2020;55(1):27–38.
10. Ford AC, Sperber AD, Corsetti M, Camilleri M. Irritable bowel syndrome. Lancet. 2020;396(10263):1675–88.
11. Werth BL, Christopher SA. Potential risk factors for constipation in the community. World J Gastroenterol. 2021;27(21):2795–817.
12. Forootan M, Bagheri N, Darvishi M. Chronic constipation: A review of literature. Med (Baltim). 2018;97(20):e10631.
13. Rollet M, Bohn T, Vahid F, On Behalf Of The Oriscav Working G. Association between dietary factors and constipation in adults living in Luxembourg and taking part in the ORISCAV-LUX 2 survey. Nutrients. 2021;14(1).
14. Tuck CJ, Vanner SJ. Dietary therapies for functional bowel symptoms: recent advances, challenges, and future directions. Neurogastroenterol Motil. 2018;30(1).
15. Meng Y, Li S, Khan J, Dai Z, Li C, Hu X, Shen Q, Xue Y. Sugar- and artificially sweetened beverages consumption linked to type 2 diabetes, cardiovascular diseases, and All-Cause mortality: A systematic review and Dose-Response Meta-Analysis of prospective cohort studies. Nutrients. 2021;13(8).
16. Popkin BM. Patterns of beverage use across the lifecycle. Physiol Behav. 2010;100(1):4–9.
17. Wang H, Jeong H, Kim NH, Kang Y, Hwang K, Lee H, Hong JH, Oh KS. Association between beverage intake and obesity in children: the Korea National health and nutrition examination survey (KNHANES) 2013–2015. Nutr Res Pract. 2018;12(4):307–14.
18. McGuire S, January U.S. Department of Agriculture and U.S. Department of Health and Human Services., Dietary Guidelines for Americans, 2010. 7th Edition, Washington, DC: U.S. Government Printing Office, 2011. Adv Nutr. 2011;2(3):293–294.
19. Malik VS, Hu FB. The role of sugar-sweetened beverages in the global epidemics of obesity and chronic diseases. Nat Rev Endocrinol. 2022;18(4):205–18.
20. Singh GM, Micha R, Khatibzadeh S, Lim S, Ezzati M, Mozaffarian D. Estimated global, regional, and National disease burdens related to Sugar-Sweetened beverage consumption in 2010. Circulation. 2015;132(8):639–66.
21. Welsh JA, Sharma AJ, Grellinger L, Vos MB. Consumption of added sugars is decreasing in the united States. Am J Clin Nutr. 2011;94(3):726–34.
22. von Philipsborn P, Stratil JM, Burns J, Busert LK, Pfadenhauer LM, Polus S, Holzapfel C, Hauner H, Rehfuess E. Environmental interventions to reduce the consumption of sugar-sweetened beverages and their effects on health. Cochrane Database Syst Rev. 2019;6(6):Cd012292.
23. Della Corte K, Fife J, Gardner A, Murphy BL, Kleis L, Della Corte D, Schwingshackl L, LeCheminant JD, Buyken AE. World trends in sugar-sweetened beverage and dietary sugar intakes in children and adolescents: a systematic review. Nutr Rev. 2021;79(3):274–88.
24. Fung TT, Malik V, Rexrode KM, Manson JE, Willett WC, Hu FB. Sweetened beverage consumption and risk of coronary heart disease in women. Am J Clin Nutr. 2009;89(4):1037–42.
25. Duffey KJ, Gordon-Larsen P, Steffen LM, Jacobs DR Jr., Popkin BM. Drinking caloric beverages increases the risk of adverse cardiometabolic outcomes in the coronary artery risk development in young adults (CARDIA) study. Am J Clin Nutr. 2010;92(4):954–9.
26. Hu FB. Resolved: there is sufficient scientific evidence that decreasing sugar-sweetened beverage consumption will reduce the prevalence of obesity and obesity-related diseases. Obes Rev. 2013;14(8):606–19.
27. Ferreira-Pêgo C, Babio N, Bes-Rastrollo M, Corella D, Estruch R, Ros E, Fitó M, Serra-Majem L, Arós F, Fiol M, Santos-Lozano JM, Muñoz-Bravo C, Pintó X, Ruiz-Canela M, Salas-Salvadó J. Frequent consumption of Sugar- and artificially sweetened beverages and natural and bottled fruit juices is associated with an increased risk of metabolic syndrome in a mediterranean population at high cardiovascular disease risk. J Nutr. 2016;146(8):1528–36.
28. Sturt J. Higher consumption of sugar-sweetened beverages is associated with increased risk of developing type 2 diabetes or metabolic syndrome. Evid Based Nurs. 2011;14(2):35.
29. Malik VS, Popkin BM, Bray GA, Després JP, Willett WC, Hu FB. Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: a meta-analysis. Diabetes Care. 2010;33(11):2477–83.
30. Ebrahimpour-Koujan S, Saneei P, Larijani B, Esmaillzadeh A. Consumption of sugar sweetened beverages and dietary Fructose in relation to risk of gout and hyperuricemia: a systematic review and meta-analysis. Crit Rev Food Sci Nutr. 2020;60(1):1–10.
31. Fu T, Chen H, Chen X, Sun Y, Xie Y, Deng M, Hesketh T, Wang X, Chen J. Sugar-sweetened beverages, artificially sweetened beverages and natural juices and risk of inflammatory bowel disease: a cohort study of 121,490 participants. Aliment Pharmacol Ther. 2022;56(6):1018–29.
32. Dan L, Fu T, Sun Y, Ruan X, Lu S, Chen J, Wang X. Associations of sugar-sweetened beverages, artificially sweetened beverages, and natural juices with cardiovascular disease and all-cause mortality in individuals with inflammatory bowel disease in a prospective cohort study. Th Adv Gastroenterol. 2023;16:17562848231207305.
33. Wang C, Zhang L, Li L. Association between selenium intake with chronic constipation and chronic diarrhea in adults: findings from the National health and nutrition examination survey. Biol Trace Elem Res. 2021;199(9):3205–12.
34. Moshfegh AJ, Rhodes DG, Baer DJ, Murayi T, Clemens JC, Rumpler WV, Paul DR, Sebastian RS, Kuczynski KJ, Ingwersen LA, Staples RC, Cleveland LE. The US department of agriculture automated Multiple-Pass method reduces bias in the collection of energy intakes. Am J Clin Nutr. 2008;88(2):324–32.
35. Bremer AA, Auinger P, Byrd RS. Relationship between insulin resistance-associated metabolic parameters and anthropometric measurements with sugar-sweetened beverage intake and physical activity levels in US adolescents: findings from the 1999–2004 National health and nutrition examination survey. Arch Pediatr Adolesc Med. 2009;163(4):328–35.

36. Bremer AA, Byrd RS, Auinger P. Differences in male and female adolescents from various Racial groups in the relationship between insulin resistance-associated parameters with sugar-sweetened beverage intake and physical activity levels. Clin Pediatr (Phila). 2010;49(12):1134–42.
37. Liu Q, Kang Y, Yan J. Association between overall dietary quality and constipation in American adults: a cross-sectional study. BMC Public Health. 2022;22(1):1971.
38. Sommers T, Mitsuhashi S, Singh P, Hirsch W, Katon J, Ballou S, Rangan V, Cheng V, Friedlander D, Iturrino J, Lembo A, Nee J. Prevalence of chronic constipation and chronic diarrhea in diabetic individuals in the united States. Am J Gastroenterol. 2019;114(1):135–42.
39. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. 2001;16(9):606–13.
40. Cai Y, Chen M, Zhai W, Wang C. Interaction between trouble sleeping and depression on hypertension in the NHANES 2005–2018. BMC Public Health. 2022;22(1):481.
41. Mugie SM, Benninga MA, Di Lorenzo C. Epidemiology of constipation in children and adults: a systematic review. Best Pract Res Clin Gastroenterol. 2011;25(1):3–18.
42. Camilleri M, Ford AC, Mawe GM, Dinning PG, Rao SS, Chey WD, Simrén M, Lembo A, Young-Fadok TM, Chang L. Chronic constipation. Nat Rev Dis Primers. 2017;3:17095.
43. Du X, Liu S, Jia P, Wang X, Gan J, Hu W, Zhu H, Song Y, Niu J, Ji Y. Epidemiology of constipation in elderly people in parts of China: A multicenter study. Front Public Health. 2022;10:823987.
44. Slining MM, Popkin BM. Trends in intakes and sources of solid fats and added sugars among U.S. Children and adolescents: 1994–2010. Pediatr Obes. 2013;8(4):307–24.
45. Cuomo R, Andreozzi P, Zito FP. Alcoholic beverages and carbonated soft drinks: consumption and Gastrointestinal cancer risks. Cancer Treat Res. 2014;159:97–120.
46. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. Am J Clin Nutr. 2006;84(2):274–88.
47. Schulze MB, Manson JE, Ludwig DS, Colditz GA, Stampfer MJ, Willett WC, Hu FB. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. JAMA. 2004;292(8):927–34.
48. Kesuma Y, Sekartini R, Timan IS, Kurniawan A, Bardosono S, Firmansyah A, Vandenplas Y. Irritable bowel syndrome in Indonesian adolescents. J Pediatr (Rio J). 2021;97(2):197–203.
49. Sandler RS, Jordan MC, Shelton BJ. Demographic and dietary determinants of constipation in the US population. Am J Public Health. 1990;80(2):185–9.
50. Włodarczyk J, Waśniewska A, Fichna J, Dziki A, Dziki Ł, Włodarczyk M. Current overview on clinical management of chronic constipation. J Clin Med. 2021;10(8).
51. Im PK, Wright N, Yang L, Chan KH, Chen Y, Guo Y, Du H, Yang X, Avery D, Wang S, Yu C, Lv J, Clarke R, Chen J, Collins R, Walters RG, Peto R, Li L, Chen Z, Millwood IY. Alcohol consumption and risks of more than 200 diseases in Chinese men. Nat Med. 2023;29(6):1476–86.
52. Kruis W, Forstmaier G, Scheurlen C, Stellaard F. Effect of diets low and high in refined sugars on gut transit, bile acid metabolism, and bacterial fermentation. Gut. 1991;32(4):367–71.
53. Zhang S, Wang R, Li D, Zhao L, Zhu L. Role of gut microbiota in functional constipation. Gastroenterol Rep (Oxf). 2021;9(5):392–401.
54. Cao H, Liu X, An Y, Zhou G, Liu Y, Xu M, Dong W, Wang S, Yan F, Jiang K, Wang B. Dysbiosis contributes to chronic constipation development via regulation of serotonin transporter in the intestine. Sci Rep. 2017;7(1):10322.
55. Khan S, Waliullah S, Godfrey V, Khan MAW, Ramachandran RA, Cantarel BL, Behrendt C, Peng L, Hooper LV, Zaki H. Dietary simple sugars alter microbial ecology in the gut and promote colitis in mice. Sci Transl Med. 2020;12(567).
56. Guerreiro S, Alçada M, Azevedo I. [Sugary drinks and glycemia]. Acta Med Port. 2010;23(4):567–78.
57. Fávaro-Moreira NC, Krausch-Hofmann S, Matthys C, Vereecken C, Vanhauwaert E, Declercq A, Bekkering GE, Duyck J. Risk factors for malnutrition in older adults: A systematic review of the literature based on longitudinal data. Adv Nutr. 2016;7(3):507–22.
58. Qin P, Li Q, Zhao Y, Chen Q, Sun X, Liu Y, Li H, Wang T, Chen X, Zhou Q, Guo C, Zhang D, Tian G, Liu D, Qie R, Han M, Huang S, Wu X, Li Y, Feng Y, Yang X, Hu F, Hu D, Zhang M. Sugar and artificially sweetened beverages and risk of obesity, type 2 diabetes mellitus, hypertension, and all-cause mortality: a dose-response meta-analysis of prospective cohort studies. Eur J Epidemiol. 2020;35(7):655–71.

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