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Soda Consumption During Ad Libitum Food Intake Predicts Weight Change

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Abstract

Soda consumption may contribute to weight gain over time. Objective data were used to determine whether soda consumption predicts weight gain or changes in glucose regulation over time. Subjects without diabetes (128 men, 75 women; mean age 34.3±8.9 years; mean body mass index [BMI] 32.5±7.4; mean percentage body fat 31.6%±8.6%) self-selected their food from an ad libitum vending machine system for 3 days. Mean daily energy intake was calculated from food weight. Energy consumed from soda was recorded as were food choices that were low in fat (<20%) or high in simple sugars (>30%). Food choices were expressed as percentage of daily energy intake. A subset of 85 subjects had measurement of follow-up weights and oral glucose tolerance (57 men, 28 women; mean follow-up time=2.5±2.1 years, range 6 months to 9.9 years). Energy consumed from soda was negatively related to age (r=–0.27, P=0.0001), and choosing low-fat foods (r=−0.35, P<0.0001), but positively associated with choosing solid foods high in simple sugars (r=0.45, P<0.0001) and overall average daily energy intake (r=0.46, P<0.0001). Energy intake from food alone did not differ between individuals who did and did not consume beverage calories (P=0.11). Total daily energy intake had no relationship with change in weight (P=0.29) or change in glucose regulation (P=0.38) over time. However, energy consumed from soda correlated with change in weight (r=0.21, P=0.04). This relationship was unchanged after adjusting for follow-up time and initial weight. Soda consumption is a marker for excess energy consumption and is associated with weight gain.

Keywords

Soda; Food intake; Sugar-sweetened beverages; Weight change; Vending machines

Although obesity rates may be stabilizing, the obesity epidemic is still widespread.[1] Over the last 2 decades, patterns of consumption of sugar-sweetened beverages (SSBs) have increased along with obesity rates in the United States.[2-4] For example, approximately 50% of US adults were drinking SSBs in 1988, and now more than 60% report consuming them.[2] Not only do more adults report drinking soda, they also report drinking more at each time of consumption. The increased consumption of SSBs has led to a significant increase in the percentage of daily energy from beverages, from 12% to 21% over the past 40 years.[3] Due

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to the parallel increase between SSBs consumption and obesity prevalence, a potential causal relationship of SSBs in development of adiposity has become of increasing interest.

Several studies indicate an association between reported SSB consumption and weight gain over time,[5-10] whereas a reduction in energy from SSBs results in weight loss over time.[11,12] Other evidence also indicates an association between reported SSB consumption and a risk for type 2 diabetes,[7,10,13] although it is unclear whether this is due to an effect of SSBs on glucose metabolism or a byproduct of weight gain. Despite these prior reports, the determination of accurate food and energy intake is difficult, and these associations need to be confirmed by alternate methodologies. Most studies use self-reported dietary intake data,[5-10] which can result in underreporting of energy intake,[14,15] and, specifically, food and beverages high in sugar may be selectively underreported.[16] Furthermore, despite findings linking energy intake from soda and weight gain or glucose regulation, little is known regarding possible mechanisms, such as lack of satiety from SSB or relationship with other food choices. The aim of this study was to use objectively gathered dietary intake data using a vending machine paradigm to determine whether there is a significant relationship between energy from soda intake and weight gain or changes in glucose regulation over time.

SUBJECTS AND METHODS

Study Population

This study was a secondary analysis of data from an ongoing natural history study of food intake at the Obesity and Diabetes Clinical Research Section of the National Institutes of Diabetes and Digestive and Kidney Diseases (NIDDK) in Phoenix, AZ. Two hundred ten volunteers participated in a study evaluating contributors to food intake between 1999 and 2011. Six subjects were excluded because they had type 2 diabetes, and one subject was excluded due to nonphysiologic weights recorded in the dataset. Two hundred three subjects were included in the cross-sectional analysis. Before participation, subject volunteers were told about the purpose of the study, and written informed consent was obtained. The protocol was approved by the Institutional Review Board of the NIDDK. All subjects were found to be healthy based on medical histories and physical examination, and free from type 2 diabetes via an oral glucose tolerance test (see next paragraph). Of the initial 203 subjects, 85 had follow-up weights and oral glucose tolerance tests at the time of follow-up. These subjects participated in other studies on our research unit and are, therefore, a convenience sample that allowed for the gathering of follow-up information.

Oral Glucose Tolerance Test

Glucose tolerance was assessed in all subject volunteers with a 75-g oral glucose test. Plasma glucose concentrations were measured using the glucose oxidase method (Beckman Instruments). None of the subjects included in the analysis had evidence of diabetes mellitus, per American Diabetes Association diagnostic criteria.[17]

Body Composition

Height was measured to the nearest centimeter using a stadiometer. Weight was measured to the nearest 0.1 kg using a calibrated digital scale. Body composition was measured by DXA (DPX-L; Lunar Corp).[18]

Vending Machine Paradigm

After admission to the research unit, subjects were fed a weight-maintaining diet for 3 days consisting of 20% of energy from protein, 30% from fat, and 50% from carbohydrate. Energy needs were calculated based on weight and sex as previously described.[19]

During the final 3 days of admission, subjects were asked to self-select food from a computer-operated vending machine , which has previously been validated and demonstrated to have good reproducibility.[20] Briefly, each subject completed a questionnaire regarding food preferences, ranking 80 different foods on a 9-point Likert scale. Subjects were also asked to report their preferred type of soda. For the days subjects selected food from the vending machine, 40 foods that the subjects had given an intermediate high ranking were made available. Each day these same 40 foods were available along with a standard group of basic foods and condiments. Water, coffee, 2% milk, orange juice, apple juice, and six 12-oz cans of the subject's soda choice were also available each day. Subjects were allowed free access to the vending machine for 23.5 hours per day for 3 days and asked to mirror their usual eating behaviors. They were instructed to eat alone and in the vending room, which contained a microwave for any necessary food preparation. They were told to return all wrappers and uneaten food to the vending machine for weighing. Using the actual weights of the foods, beverages, and condiments consumed, total energy intake and specific macronutrient intake were calculated using the CBORD Professional Diet Analyzer Program (version 4.1.11, CBORD Inc, Ithaca, NY) and the Food Processor SQL Edition (version 10.0.0, ESHA Research).

Creation of Macronutrient Categories

Each food on the vending questionnaire was categorized into one of six groups, according to the macronutrient content as a percentage of the total energy. Foods were categorized as high in fat (≥45% kcal) or low in fat (<20% kcal) and then further categorized as being high in simple sugar (≥30% kcal), high in complex carbohydrates (≥30% kcal), or high in protein (≥13% kcal). These categorizations produced six different categories of foods: high-fat/high–complex carbohydrate (HF/HC), high-fat/high-protein (HF/HP), high-fat/high-–simple sugar (HF/HS), low-fat/high–complex carbohydrate (LF/HC), low-fat/high-protein (LF/HP), low-fat/high–simple sugar (LF/HS).[21] Energy from soda was not included in any of these six groups. We further combined the HF/HS and LF/HS groups to create a group of foods that were high in simple sugars. Consumption of foods high in simple sugars was expressed as a percentage of total energy consumed. We considered choices in the LF/HC and LF/HP groups to be healthier food choices and combined them to form a “healthy” foods group, which was also expressed as a percentage of total energy. Energy from soda, juice, and milk were calculated separately. The category of “SSBs” includes energy from soda and juice, and the category of “milk and SSBs” includes energy from soda, juice, and milk combined. Although milk is also a caloric beverage, it was not classified the same as soda and juice due to other properties that may be beneficial, such as protein and calcium. Only 141 subjects had records of milk and juice data.

Statistical Analysis

All statistical analyses were done with SAS (version 9.3, SAS Institute, Inc). Unless otherwise noted, all data are expressed as mean±standard deviation. Energy intake is reported as a daily mean of the 3 vending days. The follow-up weight was determined as the weight at the most recent return visit. The follow-up fasting and 2-hour glucose values were determined as the values at the most recent follow-up visit in which the subject was not diagnosed with type 2 diabetes. Correlations between continuous variables were assessed using Spearman correlation coefficients. Comparisons between categorical variables were analyzed using χ^2 analyses. Differences in continuous variables between soda drinkers and non–soda drinkers and between subjects with and without follow-up data were analyzed using Student's *t* test. Generalized linear models were used to control for age, sex, BMI, or percentage body fat in the cross-sectional analysis and for age, sex, initial weight, and follow-up time in the longitudinal analysis. The significance level was set to 0.05.

RESULTS

Subject Characteristics

A comparison of demographic and energy intake characteristics between soda drinkers and non–soda drinkers is shown in the Table. Subjects who consumed soda were younger, had a lower fasting plasma glucose concentration, consumed more calories overall, and consumed more calories from both the HF/HS and LF/HS food categories. The lower fasting plasma glucose concentration result was not significant after adjusting for age (P=0.2). Whereas total energy consumed was different between the two groups, total energy consumed after excluding soda calories was not (see Figure 1). A categorical analysis between subjects who consumed energy from SSBs and those who did not was not done because only one subject consumed 0 kcal from beverages.

Soda Energy Intake Correlated with Concurrent Food Choices

In an analysis using the continuous rather than grouped data, energy consumed from soda positively correlated with total energy consumed (ρ=0.46, P<0.0001), energy consumed as simple sugars (ρ=0.45, P<0.0001), and energy consumed from the following groups: HF/HC (ρ=0.26, P=0.0002), HF/HP (ρ=0.24, P=0.0005), HF/HS (ρ=0.36, P<0.0001), LF/HS (ρ=0.73, P<0.0001). These relationships were still significant after adjustments for age, sex, and race. Energy intake from soda negatively correlated with age (ρ=–0.27, P=0.0001), percentage body fat (%BF) (ρ=–0.14, P=0.05), and healthy energy consumed (ρ=–0.35, P<0.0001). These relationships also remained unchanged after adjustment for sex, and race. When using SSB energy instead of soda energy, the relationships with total energy consumed and energy consumed as simple sugars remained. The correlation with simple sugars, however, is driven by the correlation with soda energy; there was no association with juice energy alone. The correlations with the food groups also remained, although the only group that correlated with juice energy alone was the LF/HS group, which indicates that the other correlations are driven by soda energy consumption. Juice consumption did not correlate with age, percentage body fat, or healthy energy consumed.

Soda Energy Intake Predicted Weight Change

Eighty-five subjects had follow-up data available. In a comparative analysis between subjects with follow-up data and subjects without follow-up data, there were no significant differences in proportions by sex or race, nor were there differences in baseline age, weight, BMI, percentage body fat, fasting glucose, 2-hour glucose, or energy consumed excluding soda energy. Subjects with follow-up data did consume more energy overall (P=0.04), more soda calories (P=0.02), and more calories from SSBs (P=0.01).

Soda energy consumed was positively correlated with change in weight (ρ=0.21, P=0.04, n=85; see Figure 2). This result remained unchanged after adjusting for age, sex, race, initial weight, and follow-up time (ρ=0.21, P=0.04). Energy from SSBs was not correlated with change in weight (ρ=0.23, P=0.08, n=59). Soda energy intake was not correlated with change in either fasting or 2-hour plasma glucose concentrations. Results were unchanged after exclusion of outliers.

DISCUSSION

As we have previously demonstrated,[20] this study shows that when people are provided unlimited access to food, they consume excess energy. However, people who drink soda consume significantly more energy than people who do not drink soda, and this additional energy is consumed primarily from soda. Furthermore, consumers of soda are more likely to choose to eat foods that contain a high percentage of fat and simple sugars and less likely to choose healthier options. These findings suggest that soda calories may not produce the same satiety as other foods/beverages and are often "addon" calories in the diet. Baseline consumption of soda was correlated with weight gain, even after adjustments for age, sex, race, initial weight, and follow-up time. In this study, there did not seem to be a relationship between soda consumption and change in fasting or 2-hour glucose levels.

Many previous studies also indicate a relationship between soda energy intake, overall energy intake, and weight gain over time.[5-10] In an analysis of diet and lifestyle factors for long-term weight gain, Mozaffarian and colleagues[8] determined that the consumption of SSBs was one of the top three factors that was independently associated with weight gain over time. Chen and colleagues[11] reported a reduction in SSB consumption resulted in significant weight loss at 6 and 18 months. The reduction in liquid, rather than solid, calories had a stronger effect on weight loss. A 1-serving per day reduction of SSBs of was associated with a 0.5-kg weight loss at 6 months and 0.7-kg weight loss at 18 months. Similar results were shown by Stookey and colleagues[12]; replacing caloric beverages with water was associated with a decrease in total energy intake, and this decrease in energy was sustained over 12 months. DellaValle and colleagues[22] reported that caloric beverages increase total energy intake without affecting satiety ratings. These studies used self-reported data or beverage manipulation in only one meal per week.

Our study uses a methodology with objective measures of both ad libitum energy intake and food choices averaged over 3 days, thus providing a comprehensive assessment of eating behaviors. This self-selecting vending machine system has been proven to be valid and highly reproducible within an individual during repeated trials.[20] Furthermore, the number of studies of longitudinal effects of soda calories is still limited. Our study adds to the prior literature by utilizing an objective methodology to confirm relationships observed with self-reported data. Our analysis also includes a good representation of both sexes and a population that is generally underrepresented in clinical research.

It is important to consider the results of this study within the context of some limitations. The vending machine paradigm is an artificial environment that is conducive to overeating because there are no financial limitations and no barriers to food consumption. Therefore, it may not be representative of eating behaviors in a free-living condition. However, the system provides advantages over traditional assessment of food intake in that external eating cues and stimuli are removed and subjects are allowed access to their own machine for 23.5 hours/day so they may eat whenever they choose. In addition, Obarzanek and Levitsky[23] found that food intake at home over 4 days was significantly correlated with food intake during a 4-day stay in a Human Research Unit, and there were no significant differences in body weight during both periods of dietary intake. Therefore, it is likely that eating in a research setting correlates with energy intake at home. Furthermore, if the vending machine paradigm is conducive to overeating, then it is probably representative of overeating at home in permissive situations (holidays, parties). The provided food is not designed to promote overeating but to allow subjects the opportunity to eat freely.

Another limitation is that we supply only six cans of one kind of soda to the subjects. Soda intake is probably more varied in free-living assessment. However, only six subjects consumed all six cans on all 3 days of vending, and there is little variation in the caloric value of the different types of soda provided to the subjects. We recognize that subjects in the longitudinal analysis were not fully representative of those not included because they consumed more energy overall, more energy from soda, and more energy from SSBs. However, the demographics between the two populations were the same; therefore, we consider the longitudinal population to still be reasonably representative of the larger study population. Finally, we were unable to adjust for fitness level or physical activity other than percentage body fat; however, subjects were sedentary while on the research unit floor, including during the minimum of 4 days prior to participating in the vending portion of the study.

Based on our results as well as the aforementioned studies, there is a clear relationship between energy consumed from soda and weight gain over time. Our results indicate that this is due primarily to the excess energy consumed from soda. However, it could also be due to soda drinkers consuming more food calories, even though food calories consumed by soda drinkers were not necessarily statistically significantly different from that of the non–soda drinkers (P=0.08). Importantly, based on our results, people who consume extra energy via beverages do not compensate by reducing energy intake from other sources in their diet. The mechanism behind this lack of compensation is unclear, but several ideas have been proposed. There is evidence that energy intake from soda fails to trigger satiety mechanisms in the body.[24] The lack of mastication[25] and the fact that beverages leave the stomach more quickly than solids may ameliorate the gastrointestinal factors[26] that signal satiety. If soda intake fails to reduce satiation, more energy is consumed in a meal and more energy consumed overall.

The consumption of soda its effect on weight could be heavily influenced by social factors.[27,28] The home environment is typically where eating habits are established, and beverage consumption may be influenced by the availability of beverages at home. Consumption of soda at meals may become an ingrained habit at a young age because of beverage consumption patterns at home.

Considering the correlation between soda consumption and the intake of foods that are high in fat and high in simple sugars, people who consume soda on a regular basis may have other unhealthy dietary habits, and soda consumption may be merely an indicator of overall dietary choices. Soda drinkers may tend to eat more foods that are energy-dense and low in nutritional value in addition to consuming an overall increased daily energy intake.

Others studies report a correlation between SSB consumption and a risk for type 2 diabetes.[7,10,13] We did not see a relationship with changes in glucose regulation or development of type 2 diabetes in our study. This lack of association could be due to the small population of people in whom type 2 diabetes developed, the relatively short follow-up time, or the younger study population.

In conclusion, soda consumption leads to weight gain due to the excess energy consumed as beverages. There does not seem to be a relationship between soda consumption and a change in fasting or 2-hour glucose. Lifestyle counseling for weight loss should include recommendations about caloric beverages, especially soda. Replacing caloric beverages with noncaloric beverages may help to prevent future weight gain, but this will have to be addressed in nutritional intervention studies.

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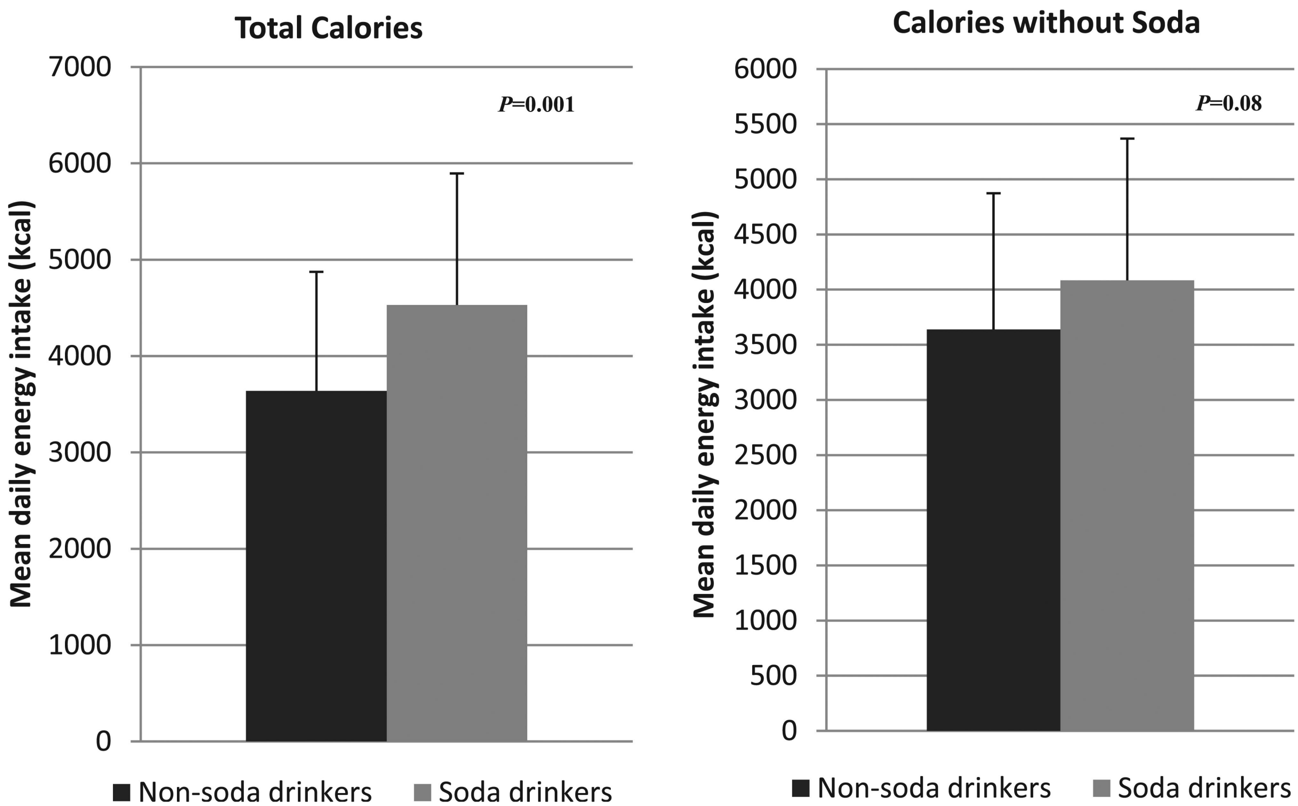

Figure 1.
Energy intake differences between soda drinkers and non–soda drinkers. χ^2 test used to determine differences between soda drinkers and non–soda drinkers.

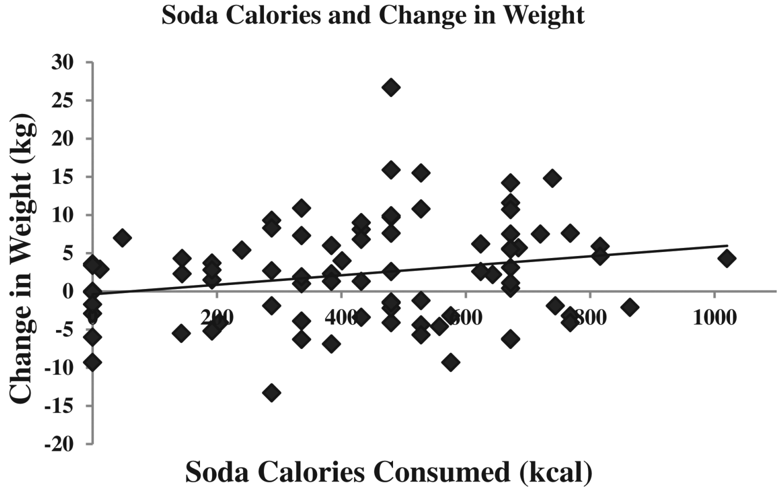

Figure 2.
Correlation between energy intake from soda and change in weight (ρ=0.21, *P*=0.04).

Table

Comparison between soda drinkers and non-soda drinkers[a]

	All subjects (N = 203)	Soda drinkers (n=173)	Non—soda drinkers (n= 30)
		mean± standard deviation	
Age (y)	34.3±8.9	33.7±8.9	38.1 ±7.8[*]
	n (%)	n	
Sex			
Male	128 (63)	112	16
Female	75 (37)	61	14
Race			
Native American	130 (64%)	114	16
White	57 (28%)	45	13
Other	16 (7%)	14	1
		mean± standard deviation	
Fasting glucose (mg/dL)		90.9±7.8	95.6±9.8[*]
Initial weight (kg)	93.7±21.9	92.9±21.7	97.9±22.7
Body mass index	32.5±7.4	32.1±7.4	34.4±7.6
Percentage body fat (%)	31.6±8.6	31.2±8.7	33.9±7.5
Daily energy consumed (kcal)	4,398±1,380	4,530±1,365	3,638±1,235[*]
Energy from soda (kcal)	379±252	445±213	0±0[*]
Energy excluding soda (kcal)	4,019±1,284	4,085±1,284	3,638±1,235
Energy from low-fat/high-simple sugar (kcal)	745±331	795±311	453±290[*]
Energy from high-fat/high-simple sugar (kcal)	809±581	845±595	601 ±449[*]

[a]Student's *t* test coefficients used for everything except sex and race between soda drinkers and non—soda drinkers. χ^2 used for sex and race differences between soda drinkers and non—soda drinkers.

[*]*P*<0.05.