Replacing Sweetened Caloric Beverages with Drinking Water Is Associated with Lower Energy Intake

Jodi D. Stookey, Florence Constant,† Christopher D. Gardner,‡ and Barry M. Popkin§*

Abstract

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Objective: Reduced intake of sweetened caloric beverages (SCBs) is recommended to lower total energy intake. Replacing SCBs with non-caloric diet beverages does not automatically lower energy intake, however. Compensatory increases in other food or beverages reportedly negate benefits of diet beverages. The purpose of this study was to evaluate drinking water as an alternative to SCBs.

Research Methods and Procedures: Secondary analysis of data from the Stanford A TO Z intervention evaluated change in beverage pattern and total energy intake in 118 overweight women (25 to 50 years) who regularly consumed SCBs (>12 ounces/d) at baseline. At baseline and 2, 6, and 12 months, mean daily beverage intake (SCBs, drinking water, non-caloric diet beverages, and nutritious caloric beverages), food composition (macronutrient, water, and fiber content), and total energy intake were estimated using three 24-hour diet recalls. Beverage intake was expressed in relative terms (percentage of beverages).

Results: In fixed effects models that controlled for total beverage intake, non-caloric and nutritious caloric beverage intake (percentage of beverages), food composition, and energy expenditure [metabolic equivalent (MET)], replacing SCBs with drinking water was associated with significant decreases in total energy intake that were sustained over time. The caloric deficit attributable to replacing SCBs with water was not negated by compensatory increases in other food or beverages. Replacing all SCBs with drinking water was associated with a predicted mean decrease in total energy of 200 kcal/d over 12 months.

Discussion: The results suggest that replacing SCBs with drinking water can help lower total energy intake in overweight consumers of SCBs motivated to diet.

Key words: women, weight-reducing diet, energy intake, dietary intake, longitudinal

Introduction

Sweetened caloric beverages (SCBs),[1] mainly soft drinks and fruit drinks, are thought to promote excess energy intake (1–7). Ecologic, cross-sectional, prospective, and experimental data indicate positive associations between SCB intake and total energy intake (1,4,8–11). In controlled experiments, SCB intake results in excess energy intake because individuals do not decrease the amount of food consumed to compensate for the calories in beverages (7,12). Presently, U.S. adults obtain over 10% of energy from SCBs (13). To reduce excess energy intake, decreased SCB intake is recommended (1,2).

Despite evidence suggesting that increases in SCB intake increase energy intake, decreases in SCB intake may not decrease total energy intake. A decrease in SCB intake may be ineffective if SCBs are replaced with caloric or non-caloric, artificially sweetened beverages. Increases in calories from beverages, such as milk, 100% juice, or diet beverages with >5 kcal/serving, may cancel out decreases in SCB calories (6,14). Increases in food intake, associated

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*Children’s Hospital Oakland Research Institute, Oakland, California; †Nestle Waters, Issy les Moulineaux, France; ‡Stanford Prevention Research Center, Stanford, California; and §Department of Nutrition, University of North Carolina, Chapel Hill, North Carolina.
Address correspondence to Jodi Dunmeyer Stookey, Children’s Hospital Oakland Research Institute, 5700 Martin Luther King Jr. Way, Oakland, CA 94609.
E-mail: jstookey@chori.org

[1] Nonstandard abbreviations: SCB, sweetened caloric beverage; NDS-R, Nutrition Data System for Research; NCC, Nutrition Coordinating Center; SD, standard deviation; SE, standard error.

Table 1. Beverage intake recommendations in the Atkins, Zone, LEARN, and Ornish diet books

Atkins (26)	"You must drink at least eight 8-oz glasses of pure water daily. This can be filtered, mineral, or spring water (not seltzer). You may also have unlimited amounts of herbal tea (without sugar), but these do not count toward your total of eight glasses" (p. 230). "Stay away from caffeine and diet sodas full of aspartame" (p. 251).
Zone (27)	"Always drink at least 8 oz of water or a sugar-free decaffeinated beverage with every meal or snack" (p. 97). Because the diet recommends three small meals and two snacks per day, this recommendation is equivalent to approximately five 8-ounce glasses of water or sugar-free decaffeinated beverages per day.
LEARN (28)	"As a rule of thumb, about 4 cups of water should be consumed for every 1000 calories eaten. For most adults this is equivalent to about 10 cups (2 1/2 quarts) of water each day" (p. 121).
Ornish (29)	No drinking water or beverage-specific recommendations listed, except: "It would be wise to limit how much [sugar] you eat . . . One can of soft drink has ten teaspoons of sugar" (p. 49).

with non-caloric, artificially sweetened beverages, may also cancel out decreases in SCB calories (15–18).

To fully eliminate excess calories from SCBs, consumers of SCBs may need to replace SCBs with drinking water. In controlled experiments where SCBs consistently result in excess energy intake, excess energy is defined relative to meals paired with drinking water (6,14,19–24). Aside from 0 calories, drinking water may differ from other beverages in terms of content (e.g., sweeteners), palatability, and/or other psychosocial food pairing or behavioral cues. Because no study has evaluated drinking water instead of SCB intake as a way to lower total energy intake in free-living individuals, it remains to be determined whether caloric benefits of drinking water apply outside the laboratory setting.

This study used data from consumers of SCBs who participated in the Stanford A TO Z weight loss trial (25) to test for an association between replacing SCBs with drinking water and decreases in total energy intake. Participants in the A TO Z trial were asked to follow specific dietary guidelines but free to choose their own foods and beverages under naturalistic conditions. Multivariable models were used to evaluate drinking water, non-caloric beverages, and nutritious caloric beverages as alternatives to SCB intake. Data from four time-points over 12 months were used to determine whether decreases in SCB calories were sustained over time or eventually negated by compensatory increases in food intake.

Research Methods and Procedures

The Stanford A TO Z study was a clinical weight loss trial that randomized overweight premenopausal women to four popular weight loss diets that are publicly available in book form (25): Dr. Atkins' New Diet Revolution (26), The Zone: A Dietary Roadmap (27), The LEARN Program for Weight Management 2000 (28), or Eat More, Weigh Less by Dr. Dean Ornish (29). Study participants attended eight classes, once per week, to discuss a portion (~1/8) of their assigned diet book. One instructor, a registered dietitian (M.S., R.D.) taught all four diet classes to minimize the variability among diet groups. Participants were expected to master the diet described in their book by the end of the 8 weeks of classes. After the 2 months of classes, study participants were followed for a period of 10 months. Dietary intake and body composition were recorded before randomization, after the 2 months of diet classes, and 6 and 12 months after randomization.

The purpose of the A TO Z trial was to compare diets that differ with respect to macronutrient profile. The Atkins diet recommends a carbohydrate intake of 20 g/d or less during the induction phase (for up to 6 months) and intake of 50 g/d or less during the ongoing weight loss phase. The Zone diet recommends a 40:30:30 distribution of carbohydrate, protein, and fat intake. The LEARN diet recommends eating less and exercising more with the help of various behavior modification strategies. It targets a carbohydrate intake of 55% to 60% of total energy intake with $<$10% of energy from saturated fat intake. The Ornish diet recommends lowering total fat intake to $\leq$10% of total energy intake. All of the diet books included general advice for all groups to accumulate ~30 minutes of moderate physical activity on most, preferably all, days of the week.

Although not the focus of the A TO Z intervention, in addition to differences in macronutrient profile, the diet books differed in terms of advice about drinking water and other beverages (see Table 1). No drinking water recommendations are noted for the Ornish program. The present longitudinal analysis takes advantage of intervention-related change in beverage intake to test for relationships between replacing SCBs with drinking water on change in total energy intake.

Study Sample

Study participants were recruited primarily from newspaper advertisements published in local newspapers. Interested premenopausal women, 25 to 50 years old, were invited to attend an orientation if they met the following criteria: BMI of 27 to 40, willingness to accept random diet assignment, stable weight over the past 2 months while not actively on a weight loss program, plans to live in the area over the next year, and available to participate in the required evaluations and interventions. Additional selection criteria included adequate English speaking, reading and writing skills to complete questionnaires and read the weekly book class assignments, and stable use of medications taken for at least 3 months. Women were excluded if they self-reported uncontrolled hypertension; type I or II diabetes; heart, renal, or liver disease; cancer or active neoplasms; uncontrolled hyperthyroidism; use of medications known to affect weight/energy expenditure; alcohol intake of 3 or more drinks/d; or psychiatric care. Women who were postmenopausal (including surgical menopause), pregnant, lactating, or planning to become pregnant over the next year were also excluded.

Of the women who met all selection criteria ($n = 311$), 131 reported regular intake of SCBs (≥12 ounces/d or ≥1 can of soda/d). Of those, 121 attended the diet classes and had complete dietary intake data for at least two time-points, baseline and 2 months. The present study sample ($n = 118$) excludes two individuals who self-reported poor general health and one person with an implausibly low 3-day mean energy intake (<500 kcal/d). Data were available for 118, 110, and 96 persons at the 2-, 6-, and 12-month follow-ups, respectively. All participants provided written informed consent. The study was approved by the Stanford University Human Subjects Committee.

Diet Assessment

Dietary intake data were collected at four time-points, at baseline and 2, 6, and 12 months. At each time-point, dietary intake data were obtained using three unannounced, telephone-administered, 24-hour dietary recalls, collected on 2 non-consecutive weekdays and 1 weekend day within a 3-week period. The dietary recalls were collected and converted to nutrient intake estimates using Nutrition Data System for Research (NDS-R) software developed by the Nutrition Coordinating Center (NCC), University of Minnesota, Minneapolis, MN [versions 4.05.33 (2002) and 4.06.34 (2003)]. The interviewers were trained and certified by the NCC in Minneapolis and were either registered dietitians or R.D. eligible. Study participants were given a food amounts booklet, provided by NDS, with images of wedges, circles, thicknesses, glasses, mounds, bowls, and portions of meat, chicken, and fish to facilitate portion size estimation. As per the NDS training, the interviewers probed for intake of drinking water and other beverages. Each food and beverage consumed was coded separately. The NDS system has a comprehensive nutrient composition database of over 18,000 items, including 8000 brand name foods and many ethnic foods. Foods or beverages that were not in the database were located, and their caloric and nutrient content added to the database manually.

Each food and beverage reported was classified as a food, drinking water, non-caloric (non-water) beverage, nutritious caloric beverage, or SCB, consistent with NCC food group codes available in the NDS and beverage groups of the Beverage Guidance panel (2). The drinking water group included tap water, bottled spring water, mineral water, soda water, seltzer water, and unsweetened sparkling or carbonated waters. The non-caloric beverage group included unsweetened plain teas and coffees, diet sodas, diet juices, and diet teas and coffees (<5 kcal or 21 kJ per serving). The nutritious caloric beverage group included 100% fruit juices, vegetable juices, milks, and alcohol. The SCB group included soda pop, soft drinks, sweetened juices, flavored drinks, sweetened milks, sports drinks, sweetened coffees, sweetened teas, and cocoa.

Three-day mean daily intakes of drinking water, sweetened caloric, nutritious caloric, and non-caloric beverages were calculated for each time-point. Beverage intake was expressed in absolute terms (ounces) and a percentage of total beverage intake. Three-day mean total energy intake, food macronutrient (expressed as a percentage of energy), water, and fiber (grams per 100 grams of food) content were calculated.

Physical Activity

Information about physical activity was collected at baseline and 2, 6, and 12 months. Physical activity was assessed using the Stanford Seven-Day Physical Activity Recall interview (30,31). An interviewer probed for the time spent sleeping and doing moderate, hard, and very hard physical activity and the intensity and duration of each activity. Energy expenditure (kilocalories per kilogram per day) was estimated from the time spent in each activity multiplied by the metabolic equivalent (1 metabolic equivalent = 1 kcal/kg per hour) for each activity.

Statistical Analyses

All analyses were carried out using STATA statistical software (StataCorp LP., College Station, TX). To account for the A TO Z study design, change in dietary intake was evaluated over 2 and 12 months. The A TO Z study design prescribed dietary change over 2 months of diet classes and diet maintenance over 10 months of follow-up. Except for an increase in carbohydrate intake (from ≤20 to ≤50 grams carbohydrate/d at the end of the induction phase) for the Atkins group at some point after the 2-month time-point, dietary change was not prescribed between the 2- and 12-month follow-ups.

To evaluate change over the 2 months of diet classes, the bivariate (crude) relationships between change in SCB intake and change in energy intake and change in drinking water and change in energy intake were described, respectively. A difference model was used to combine the data and test for an association between replacing SCBs with drinking water and decreases in total energy intake, controlling for concurrent changes in other beverage intake, food composition, and energy expenditure. The dependent variable in the difference model was change in energy intake. The independent variables were all change variables: change in SCB intake (percentage of beverages), change in non-caloric beverage intake (percentage of beverages), change in nutritious caloric beverage intake (% of beverages), change in total beverage intake (ounces), change in food fat, protein, and carbohydrate content (percentage of energy), change in food fiber and food water content (grams per 100 grams food), and change in energy expenditure. In addition to controlling for multiple time-varying covariates, by allowing each person to act as her own control, the difference model also powerfully controlled for all observed and unobserved within-person time-invariant variables.

The difference model tested for an association between replacing SCBs with drinking water and decreases in total energy intake because the SCB, non-caloric beverage, and nutritious caloric beverage variables were expressed in relative terms (as percentage of total beverage intake). Holding constant the total ounces of beverages consumed, the proportion of beverages from non-caloric beverages, and the proportion of beverages from nutritious caloric beverages, a decrease in the proportion of beverages from SCBs necessarily implies a corresponding increase in the proportion of beverages from drinking water (the reference category, left out of the model); see ref. 32 for discussion of models with variables expressed in relative terms. The difference model estimated the average within-person change in total energy intake over 2 months associated with replacing 1 unit of SCBs (1% of beverages) with drinking water.

To evaluate changes in beverage and total energy intake over 12 months, a fixed effects model with data from all time-points was used (xtreg, fe in Stata). The dependent variable in the fixed effects model was total energy intake. The independent variables were: SCB intake (percentage of beverages), non-caloric beverage intake (percentage of beverages), nutritious caloric beverage intake (percentage of beverages), total beverage intake (ounces), food fat, protein, and carbohydrate content (percentage of energy), food fiber and water content (grams per 100 grams food), and energy expenditure. Like the difference model, with SCB, non-caloric and nutritious caloric beverage intake expressed in relative terms (percentage of beverages), the fixed effect model estimated the average within-person change in total energy intake associated with replacing 1 unit of SCBs (1% of beverages) with drinking water. To determine whether/how the effect of change in SCBs depended on the choice of referent beverage, the fixed effect model was also specified with different beverage categories as referent (i.e., the non-caloric or nutritious caloric category left out of the model).

Like the difference model, in addition to controlling for within-person changes in other beverage intake, food composition, and energy expenditure, the fixed effects model also powerfully controlled for within-person time-invariant factors by allowing each individual to act as her own control. Unlike the difference model, which involved data from only two time-points, the fixed effects model included data from all four time-points. Any missing data were assumed missing at random or missing due to unobserved individual characteristics (controlled in the model).

The fixed effect model estimated the average difference in total energy intake over time associated with replacing 1 unit of SCBs (1% of beverages) with drinking water. To illustrate the average difference in energy intake over time associated with replacing multiple units of SCBs with drinking water, the model was used to predict the average decreases in energy intake over time (by invoking model simulations) associated with replacing none, half, or all SCBs with drinking water, controlling for all covariates (predict command in Stata). Predictions were generated using each individual's observed SCB intake, SCB intake/2, and SCB − SCB intake, respectively.

Analogous to experiments on this topic (7,12), the models in this study controlled the total beverage ounces, the beverage composition, and food composition and allowed the amount of food consumed to vary. One determinant of total energy intake must be allowed to vary to avoid a linear combination of variables that simply sum to total energy intake (i.e., the amount of beverages consumed × beverage composition + amount of food consumed × food composition). Based on this model specification, compensatory increases in the amount of food consumed might cancel out decreases in SCB calories. If replacing SCBs with drinking water is not associated with lower total energy intake in this study, then compensatory increases in the amount of food consumed can be inferred from the models.

Although the difference and fixed effects models controlled for within-person non-time-varying factors, including intervention diet group (observed and unobserved factors that do not change over time for an individual cancel out when differenced and drop out of the models) to check whether observed associations might be attributable to individuals clustered in any particular intervention group, the fixed effect model was stratified by diet group. A mixed model (xtmixed) that allowed non-time-varying fixed effects for the intervention diet groups was also fit.

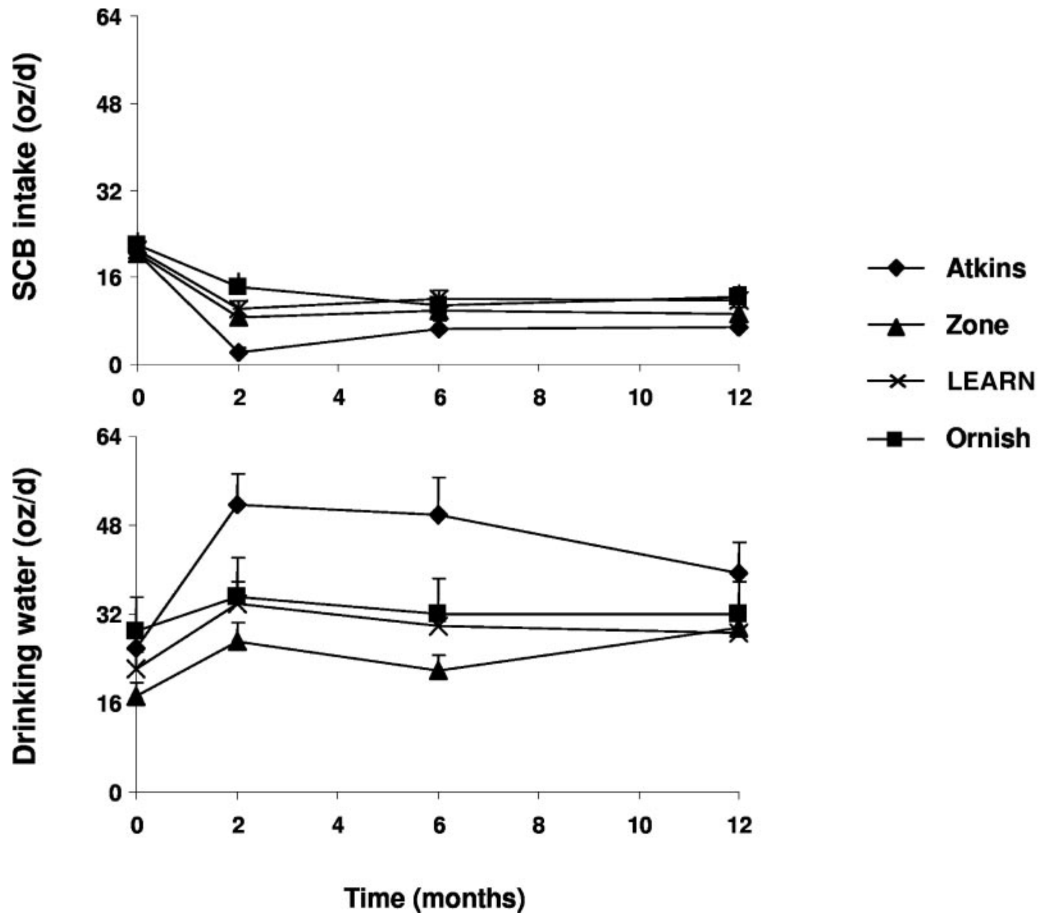

Figure 1: Intake of SCBs and drinking water at baseline and 2, 6, and 12 months by diet intervention group. Beverage intake data were available for 118, 118, 110, and 96 persons at baseline and 2, 6, and 12 months, respectively. To convert ounces to grams, multiply by 29.6.

Results

Figure 1 shows SCB and water intake at baseline and 2, 6, and 12 months, stratified by A TO Z diet intervention group. At baseline SCB and water intake did not differ by diet group. Between baseline and 2 months, SCB intakes decreased significantly, and water intakes increased significantly within each diet group. At 2 and 6 months, the changes in SCB and water intake were significantly greater for women following the Atkins diet. Intake of non-caloric beverages did not differ significantly by diet group at any time-point (data not shown).

Given the similar pattern of beverage intake across diet groups, the diet groups were combined. Mean beverage, food, and energy intake for the whole sample at baseline and 2, 6, and 12 months are summarized in Table 2. At baseline, intake of SCBs ranged from 12 to 56 ounces/d (350 to 1642 g/d, ~1 to 5 12-ounce servings). SCBs accounted for ~60% of the total kilocalories from beverages (352 kcal/d). Intake of drinking water ranged from 0 to 5284 g/d (~11 16-ounce glasses). At baseline, 5% of the sample reported no drinking water; 30% drank <12 ounces/d.

Over the 2 months of diet classes, SCB intake was halved. Change in SCB intake ranged from −48 to +30 ounces {−1411 to +877 grams, with a mean [standard deviation (SD)] of −371 (362) g}. In relative terms, change in SCB intake ranged from −84% to +54% of beverage intake [mean (SD), −19% (21%)]. At the 2-month follow-up, 27% of the sample reported no intake of SCBs. Among those still consuming SCBs, the mean (SD) change in SCB intake was −12% (19%), the mean (SD) intake was 13 (10) ounces/d [389 (297) g/d], and the mean (SD) energy intake from SCBs was 95 (95) kcal/d.

Over the 2 months of classes, intake of drinking water increased as a proportion of beverages by an average (SD) 18% (24%). Change in drinking water ranged from a decrease in intake of 1896 grams to an increase in intake of 2508 grams (~5 16-ounce glasses of water), from −33% to +74% of beverages. The majority (84%) of individuals who decreased SCB intake increased water intake. Among those who decreased SCB intake, the average increase in drinking water was +513 (685) g or +23% (22%) of beverages. Among those who decreased SCB intake, 51% increased

Table 2. Mean (SD) dietary intake and energy expenditure at baseline, 2, 6, and 12 months

	Baseline	2 months	6 months	12 months
SCBs				
(ounces/d)	21 (9)	9 (10)*	10 (10)*	10 (9)*
(% of Beverages)	37 (17)	18 (20)*	20 (20)*	17 (17)*
Drinking water				
(ounces/d)	24 (22)	36 (30)*	33 (29)*	34 (25)*
(% of beverages)	33 (20)	52 (28)*	48 (27)*	52 (24)*
Non-caloric beverages				
(ounces/d)	12 (10)	11 (11)	13 (12)	14 (12)
(% of beverages)	18 (15)	20 (19)	22 (20)*	22 (19)*
Nutritious caloric beverages				
(ounces/d)	8 (7)	6 (6)*	6 (6)*	6 (6)*
(% of beverages)	12 (11)	11 (11)	10 (9)	10 (10)
Total beverage (ounces/d)	64 (27)	63 (30)	62 (31)	63 (26)
SCB energy (kcal/d)	214 (138)	69 (91)*	79 (84)*	80 (102)*
Food energy (kcal/d)	1697 (543)	1362 (404)*	1467 (409)*	1467 (469)*
Food fat (% of energy)	39 (7)	38 (13)	39 (11)	38 (11)
Food protein (% of energy)	17 (4)	23 (7)*	20 (6)*	19 (5)*
Food water (g/100 g)	64 (8)	70 (7)*	67 (8)*	69 (7)*
Food fiber (g/100 g)	2 (1)	2 (1)	2 (1)	2 (1)
Energy expenditure (kcal/kg per day)	34 (3)	35 (2)*	35 (2)	35 (3)*
Total energy (kcal/d)	2054 (571)	1528 (455)*	1657 (443)*	1646 (505)*

SD, standard deviation; SCB, sweetened caloric beverage. Dietary intake data were available for 118, 118, 110, and 96 persons at baseline and 2, 6, and 12 months, respectively. Fixed effect models with levels of time as independent variable were used to compare the 2-, 6-, and 12-month intakes with baseline intake.
* p value < 0.05 for comparison with baseline intake.

intake of non-caloric diet beverages, although the magnitude of change in non-caloric beverages was small [+38 (292) g or +4% (18%)].

Despite recidivism over 12 months of follow-up, SCB intake remained significantly lower relative to baseline [−17% (17%) of beverages). Intake of drinking water remained significantly higher relative to baseline [+15% (24%) of beverages].

Over the 2 months of diet classes, energy intake decreased for the majority of subjects (87%). On average, total energy decreased by 526 (544) kcal/d. Although mean (SD) energy intake increased slightly between the 2- and 6-month time-points, a significant decrease relative to baseline of >400 kcal/d was maintained from the 2- to 12-month follow-up. Energy from food decreased by an average 335 (511) kcal/d from baseline to 2 months. It increased by an average 105 (432) kcal/d between the 2- and 6-month follow-ups and then remained stable at 1467 kcal/d until the 12-month follow-up. At 12 months, energy from food was 230 kcal/d lower than at baseline.

In unadjusted analyses, decreases in SCB intake between baseline and the 2-month assessment were significantly and linearly associated with decreases in total energy intake (Table 3). Increases in drinking water over this same period were also significantly and linearly associated with decreases in energy intake.

A difference model was fit to determine whether replacing caloric beverages with drinking water was associated with decreases in energy intake over the 2 months of classes, independent of concurrent changes in other beverage intake, food composition, and energy expenditure. Holding constant the macronutrient, water, and fiber content of foods consumed, each 1 unit of SCBs (% of beverage units) replaced with 1 unit of drinking water (% of beverage units) was associated with a significant 4 (1) kcal/d decrease in total energy intake. Respecifying the model with non-caloric or nutritious caloric beverages as referent, replacing SCBs with non-caloric or nutritious caloric beverages was not associated with significant change in energy intake.

Table 3. Change in beverage intake from baseline to 2 months by change in total energy intake over the same period (n = 118)

	Change in total energy intake from baseline to 2 months (kcal)			
	$\Delta < -1000$ (n = 16) [mean (SD)]	$-1000 \leq \Delta < -500$ (n = 43) [mean (SD)]	$-500 \leq \Delta < 0$ (n = 44) [mean (SD)]	$0 \leq \Delta$ (n = 15) [mean (SD)]
Change in SCBs (% of beverages)	−25 (16)	−21 (16)	−19 (25)	−5 (26)*
Change in drinking water (% of beverages)	27 (16)	23 (20)	15 (27)	4 (26)*
Change in non-caloric beverages (% of beverages)	1 (16)	1 (15)	5 (21)	−3 (16)
Change in nutritious beverages (% of beverages)	−3 (13)	−4 (13)	−1 (11)	3 (12)
Change in all beverage intake (ounces)	−1 (14)	−2 (28)	−0.3 (22)	−3 (17)

SD, standard deviation; SCB, sweetened caloric beverage. Δ = energy intake at 2 months − energy intake at baseline.
* p Value < 0.05 for test for linear trend across four levels. All statistical tests were based on robust standard errors.

Model simulations were run to illustrate the effect of replacing multiple units of SCBs with drinking water over the 2-month period. The predicted mean changes in energy intake if the sample replaced none, half, or all SCBs with water (holding constant other beverage intake, food composition, and energy expenditure) were 0, −73, and −147 kcal/d, respectively.

Fixed effect models were next used to test for associations between beverage intake and energy intake over time. Regression coefficients from these models (see Table 4) represent the difference in total energy intake associated with replacing SCBs with drinking water (Model 1), non-caloric beverages (Model 2), or nutritious caloric beverages (Model 3). Controlling the total beverage ounces, food

Table 4. Regression coefficients from fixed effect models testing for associations between beverage intake and total energy intake over 12 months of follow-up (n = 118)

	Mean total energy intake (kcal/d)		
	Model 1 [β (SE)]	Model 2 [β (SE)]	Model 3 [β (SE)]
SCBs (% of beverages)	9 (2)*	6 (2)*	1 (3)
Drinking water (% of beverages)	Ref	−3 (2)	−8 (3)*
Non-caloric beverages (% of beverages)	3 (2)	Ref	−5 (3)
Nutritious caloric beverages (% of beverages)	8 (3)*	5 (3)	Ref

SE, standard error; SCB, sweetened caloric beverage. All models included data from all time-points and controlled for non-time-varying factors and within-person changes in the amount of beverages consumed, food composition, and energy expenditure. Drinking water is the reference category in Model 1. The regression coefficients for Model 1 represent the increases in total energy intake associated with drinking SCBs, non-caloric, or nutritious caloric beverages instead of drinking water. Increasing SCB intake (decreasing water intake) by 1 unit is associated with an increase in total energy of 9 kcal/d. Increasing nutritious caloric beverages (decreasing water intake) by 1 unit is associated with an increase of 8 kcal/d. The effect of replacing 1 unit of SCB with plain water (i.e., decrease SCB and increase water) is the inverse coefficient (−9 kcal/d). The reference categories in Models 2 and 3 are non-caloric (non-water) beverages and nutritious caloric beverages, respectively. Model 2 estimates the effect of replacing SCBs with non-caloric beverages. Model 3 estimates the effect of replacing SCBs with a nutritious caloric beverage.
* p Value < 0.05 for comparison with the reference category.

composition, and energy expenditure, each 1 percentage unit of SCBs replaced by drinking water was associated with a 9 (2) kcal/d lower energy intake over time (Model 1). Based on this model, replacing all SCBs with drinking water was associated with a mean total energy intake over time of 1516 kcal/d, whereas replacing one-half or none of the SCBs with water was associated with predicted mean energy intakes of 1615 and 1715, respectively. Replacing all SCBs with water was associated with a predicted total energy intake that was 200 kcal/d lower over time. The results of Models 2 and 3 indicate smaller decreases in total energy intake if SCBs are replaced with non-caloric or nutritious caloric beverages. The caloric benefit of decreasing SCBs is 30% smaller (6 vs. 9 kcal/d) if the SCBs are replaced with non-caloric diet beverages than if replaced with plain water. Model 3 indicates no caloric benefit of decreasing SCBs if SCBs are replaced with nutritious caloric beverages.

Considering that changes in SCB and water intake were significantly greater for the Atkins group (Figure 1), Model 1 in Table 3 was stratified by diet group to see whether any particular intervention diet was driving the observed association. Diet group did not explain the observed association. Replacing SCBs with drinking water was significantly associated with decreases in total energy intake within each diet group. For the Atkins, Zone, LEARN, and Ornish diet groups, the effect of replacing one unit of SCBs with plain water was: β [standard error (SE)] = 13 (4) kcal/d ($p = 0.005$), β (SE) = 8 (3) kcal/d ($p = 0.01$), β (SE) = 11 (4) kcal/d ($p = 0.004$), and β (SE) = 6 (3) kcal/d ($p = 0.08$), respectively. The corresponding regression coefficient from a mixed model with all of the same variables plus fixed effects for each diet group was β (SE) = 7 (1) kcal/d ($p < 0.001$).

Discussion

Consistent with results from many short-term experiments (6,14,19–24), the results of this study suggest that replacing SCBs with drinking water may be an effective way to lower total energy intake in free-living individuals. Consumers of SCBs, following prescribed diets as part of the Stanford A TO Z weight loss intervention, significantly decreased SCB intake from approximately two cans of soda per day to less than one can per day and increased drinking water from one-third to one-half of beverage intake. Replacing SCBs with drinking water was associated with a significant decrease in total energy intake that was sustained over 12 months of follow-up.

The present study evaluated change in beverage pattern. Correlated changes in SCB intake and drinking water were studied in multivariable models that controlled for changes in other beverage intake. Unlike studies that target absolute change in one kind of beverage without regard for correlated change in other beverages (16,33), the reference category (or what people drink when not drinking the target beverage) was made explicit in this study.

The results of this study show that the effect of change in SCB intake depends on correlated change in other beverage intake. The caloric benefit of decreasing SCBs was eliminated if the SCBs were replaced with nutritious caloric beverages and considerably reduced if the SCBs were replaced with non-caloric beverages. The caloric benefit associated with replacing SCBs with non-caloric beverages was 30% smaller than that associated with drinking water. Specifying drinking water as the alternative to SCBs may allow a maximal caloric deficit because other beverages contain more calories or sweeteners that, although controversial, may stimulate appetite (34–37).

Compensatory increases in the amount of food consumed did not cancel out decreases in energy intake associated with replacing SCBs with drinking water. At baseline, SCBs contributed an average 214 kcal/d. Replacing all SCBs with drinking water was associated with a predicted mean decrease in total energy of 202 kcal/d over time. The lack of compensatory increases in food intake may reflect consistent, null effects of drinking water on the amount of food consumed (14,24,38,39). Alternatively, the lack of compensatory increases in food intake may reflect conscious effort on the part of study participants to consume particular amounts of foods specified in the diet books. In reviews of the literature, Rolls (36) and Renwick (40) conclude that non-caloric beverages may only lower energy intake if individuals consciously avoid replacing SCB calories with increased intake of other items. Given that individuals in this study agreed to participate in a year-long weight loss intervention trial, the study population may have been highly motivated to resist increases in food intake.

Although motivation to adhere to a diet might explain the association between beverage change and energy intake in this study, the observed association was not attributable to any particular intervention diet or food intake profile. The association between beverage change and energy intake was observed for each type of diet, Atkins, Zone, LEARN, and Ornish. It was observed with and without control for correlated changes in all key determinants of energy density, food macronutrient, water, and fiber composition.

This study focused on SCB intake because SCBs are implicated in the obesity epidemic and related negative health outcomes, including diabetes, impaired bone health, and dental carries (1–4). Although all types of caloric beverages result in excess energy intake compared with water in short-term experiments (7,12), intake of other caloric beverages has not increased over time to the same degree as SCB intake. Increases in SCB intake and obesity are particularly worrisome among children and adolescents (1,13,41). The present focus on SCBs is consistent with current recommendations to reduce intake of nutrient-poor SCBs and moderate intake of nutrient-rich caloric beverages (e.g., milk) (1,2).

The association between decreases in SCB intake and decreases in energy intake in this study mirrors reported associations between increases in SCB intake, increases in energy intake, and weight gain (1). In the A TO Z cohort, replacing SCBs with drinking water is associated with significant reductions in body weight, percentage body fat, and waist circumference (Stookey JD, Florence C, Gardner CD, Popkin BM, unpublished data).

The results of this study strongly suggest that replacing SCBs with drinking water may be an effective way to reduce energy intake in consumers of SCBs motivated to change their diet to reduce caloric intake. Although the study was not a randomized trial of change in beverage effects, potential confounding variables were controlled in rigorous longitudinal models. Replacing SCBs with water appeared beneficial regardless of diet type or food composition. Although randomized trials are needed to confirm benefits of drinking water for consumers of SCBs and other population groups, more generally, the results nevertheless suggest that beverage change may be a powerful complement to increased intake of energy dilute foods and physical activity as a strategy to reduce excess energy intake. Given the high prevalence of SCB intake among children, adolescents, and young adults (13), interventions to replace SCBs with water may be particularly important for the prevention of pediatric and young adult obesity. Considering public confusion about the benefits of drinking water for appetite control, disparate popular advice regarding beverages for dieting (Table 1) and ambiguity about appropriate alternatives to SCBs in scientific recommendations (1,2), rather than promoting "decreases in SCB intake," it may be important for public health campaigns to promote "drinking water instead of SCBs."

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References

1. **Malik VS, Schulze MB, Hu FB.** Intake of sugar-sweetened beverages and weight gain: a systematic review. *Am J Clin Nutr*. 2006;84:274–88.
2. **Popkin BM, Armstrong LE, Bray GM, Caballero B, Frei B, Willett WC.** A new proposed guidance system for beverage consumption in the United States. *Am J Clin Nutr*. 2006; 83:529–42.
3. **Popkin BM, Nielsen SJ.** The sweetening of the world's diet. *Obes Res*. 2003;11:1325–32.
4. **Bray GA, Nielsen SJ, Popkin BM.** Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. *Am J Clin Nutr*. 2004;79:537–43.
5. **Johnson RK, Frary C.** Choose beverages and foods to moderate your intake of sugars: the 2000 dietary guidelines for Americans: what's all the fuss about? *J Nutr*. 2001;131:2766–71S.
6. **Almiron-Roig ECY, Drewnowski A.** Liquid calories and the failure of satiety: how good is the evidence? *Obes Rev*. 2003; 4:201–12.
7. **DiMeglio DP, Mattes RD.** Liquid versus solid carbohydrate: effects on food intake and body weight. *Int J Obes Relat Metab Disord*. 2000;24:794–800.
8. **Anand RS, Basiotis, PP.** *Is Total Fat Consumption Really Decreasing? Nutrition Insights 5*. Washington, DC: USDA Center for Nutrition Policy and Promotion; 1998.
9. **Harnack L, Stang J, Story M.** Soft drink consumption among US children and adolescents: nutritional consequences. *J Am Diet Assoc*. 1999;99:436–41.
10. **Toriano RP BR, Carroll MD, Bialostosky K.** Energy and fat intakes of children and adolescents in the United States: data from the National Health and Nutrition Examination Surveys. *Am J Clin Nutr*. 2000;72 (suppl):1343–53S.
11. **Rajeshwari R, Yang S-J, Nicklas TA, Berenson GS.** Secular trends in children's sweetened-beverage consumption (1973 to 1994): The Bogalusa Heart Study. *J Am Diet Assoc*. 2005; 105:208–14.
12. **Mattes RD.** Dietary compensation by humans for supplemental energy provided as ethanol or carbohydrate in fluids. *Physiol Behav*. 1996;59:179–87.
13. **Nielsen SJ, Popkin BM.** Changes in beverage intake between 1977 and 2001. *Am J Prev Med*. 2004;27:205–10.
14. **DellaValle DM, Roe LS, Rolls BJ.** Does the consumption of caloric and non-caloric beverages with a meal affect energy intake? *Appetite*. 2005;44:187–93.
15. **Holt SH, Sandona N, Brand-Miller JC.** The effects of sugar-free vs sugar-rich beverages on feelings of fullness and subsequent food intake. *Int J Food Sci Nutr*. 2000;51:59–71.
16. **Blackburn GL, Kanders BS, Lavin PT, Keller SD, Whatley J.** The effect of aspartame as part of a multidisciplinary weight-control program on short- and long-term control of body weight. *Am J Clin Nutr*. 1997;65:409–18.
17. **Foltin RW, Fischman MW, Moran TH, Rolls BJ, Kelly TH.** Caloric compensation for lunches varying in fat and carbohydrate content by humans in a residential laboratory. *Am J Clin Nutr*. 1990;52:969–80.
18. **Porikos KP, Hesser MF, van Itallie TB.** Caloric regulation in normal-weight men maintained on a palatable diet of conventional foods. *Physiol Behav*. 1982;29:293–300.

19. **Rodin J.** Comparative effects of fructose, aspartame, glucose, and water preloads on calorie and macronutrient intake. *Am J Clin Nutr*. 1990;51:428–35.
20. **Hagg A, Jacobson T, Nordlund G, Rossner S.** Effects of milk or water on lunch intake in preschool children. *Appetite*. 1998;31:83–92.
21. **Beridot-Therond ME, Arts I, Fantino M, De La Gueronniere V.** Short-term effects of the flavour of drinks on ingestive behaviours in man. *Appetite*. 1998;31:67–81.
22. **Poppitt SD, Eckhardt JW, McGonagle J, Murgatroyd PR, Prentice AM.** Short-term effects of alcohol consumption on appetite and energy intake. *Physiol Behav*. 1996;60:1063–70.
23. **Van Wymelbeke V, Beridot-Therond ME, de La Gueronniere V, Fantino M.** Influence of repeated consumption of beverages containing sucrose or intense sweeteners on food intake. *Eur J Clin Nutr*. 2004;58:154–61.
24. **Engell D.** Effects of beverage consumption and hydration status on caloric intake. In: Mariott BM, ed. *Not Eating Enough.* Washington, DC: Institute of Medicine; 1995, pp. 217–38.
25. **Gardner CD, Kiazand A, Alhassan S, et al.** Comparison of the Atkins, Zone, Ornish, and LEARN diets for change in weight and related risk factors among overweight premenopausal women: The ATOZ Weight Loss Study: a randomized trial. *JAMA*. 2007;297:969–77.
26. **Atkins R.** *Dr. Atkins' NEW Diet Revolution.* New York, NY: Avon Books Inc.; 1992.
27. **Sears B, Lawren W.** *The Zone: A Dietary Roadmap.* New York, NY: Harper Collins Inc.; 1995.
28. **Brownell KD.** *The LEARN Manual for Weight Management.* Dallas, TX: American Health Publishing Company; 2000.
29. **Ornish D.** *Eat More, Weigh Less.* New York, NY: Harper Collins; 2001.
30. **Blair SN, Haskell WL, Ho P, et al.** Assessment of habitual physical activity by a seven-day recall in a community survey and controlled experiments. *Am J Epidemiol.* 1985;122:794–804.
31. **Sallis JF, Haskell WL, Wood PD, et al.** Physical activity assessment methodology in the Five-City Project. *Am J Epidemiol*. 1985;121:91–106.
32. **Willett W.** Implications of total energy intake for epidemiologic analyses. In: *Nutritional Epidemiology.* New York, NY: Oxford University Press; 1990, pp. 245–71.
33. **Raben A, Vasilaras TH, Moller AC, Astrup A.** Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. *Am J Clin Nutr*. 2002;76: 721–9.
34. **Blundell JE, Hill AJ.** Paradoxical effects of an intense sweetener (aspartame) on appetite. *Lancet*. 1986;1:1092–3.
35. **Rogers PJ, Blundell JE.** Separating the actions of sweetness and calories: effects of saccharin and carbohydrates on hunger and food intake in human subjects. *Physiol Behav*. 1989;45: 1093–9.
36. **Rolls BJ.** Effects of intense sweeteners on hunger, food intake, and body weight: a review. *Am J Clin Nutr*. 1991;53: 872–8.
37. **Drewnowski A.** Intense sweeteners and energy density of foods: implications for weight control. *Eur J Clin Nutr*. 1999; 53:757–63.
38. **Rolls BJ, Bell EA, Thorwart ML.** Water incorporated into a food but not served with a food decreases energy intake in lean women. *Am J Clin Nutr*. 1999;70:448–55.
39. **Rolls BJ, Kim S, Fedoroff IC.** Effects of drinks sweetened with sucrose or aspartame on hunger, thirst and food intake in men. *Physiol Behav*. 1990;48:19–26.
40. **Renwick AG.** Intense sweeteners, food intake, and the weight of a body of evidence. *Physiol Behav*. 1994;55:139–43.
41. **Ogden CL, Flegal KM, Carroll MD, Johnson CL.** Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA*. 2002;288:1728–32.