nature publishing group

Drinking Water Is Associated With Weight Loss in Overweight Dieting Women Independent of Diet and Activity

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Background: Data from short-term experiments suggest that drinking water may promote weight loss by lowering total energy intake and/or altering metabolism. The long-term effects of drinking water on change in body weight and composition are unknown, however.

Objective: This study tested for associations between absolute and relative increases in drinking water and weight loss over 12 months.

Methods and Procedures: Secondary analyses were conducted on data from the Stanford A TO Z weight loss intervention on 173 premenopausal overweight women (aged 25–50 years) who reported <1 l/day drinking water at baseline. Diet, physical activity, body weight, percent body fat (dual-energy X-ray absorptiometry), and waist circumference were assessed at baseline, 2, 6, and 12 months. At each time point, mean daily intakes of drinking water, noncaloric, unsweetened caloric (e.g., 100% fruit juice, milk) and sweetened caloric beverages, and food energy and nutrients were estimated using three unannounced 24-h diet recalls. Beverage intake was expressed in absolute (g) and relative terms (% of beverages). Mixed models were used to test for effects of absolute and relative increases in drinking water on changes in weight and body composition, controlling for baseline status, diet group, and changes in other beverage intake, the amount and composition of foods consumed and physical activity.

Results: Absolute and relative increases in drinking water were associated with significant loss of body weight and fat over time, independent of covariates.

Discussion: The results suggest that drinking water may promote weight loss in overweight dieting women.

Obesity (2008) **16,** 2481–2488. doi:10.1038/oby.2008.409

INTRODUCTION

Data from short-term controlled experiments suggest that drinking water may promote weight loss. Drinking water *vs. no beverage* increases energy expenditure and rates of lipolysis (1–4). Drinking water *instead of* caloric beverages lowers total energy intake by eliminating beverage calories (5–16). Although *absolute* increases in drinking water may promote weight loss by altering metabolism, and *relative* increases in drinking water may promote weight loss by lowering total energy intake, no studies have tested for long-term effects of drinking water on changes in body weight or composition. It is unknown whether drinking water promotes weight loss over time under free-living conditions, independent of diet and activity, or whether water has benefits distinct from other unsweetened or noncaloric beverages.

This study took advantage of data from the Stanford A TO Z weight loss intervention to determine whether increased intake of drinking water was associated with weight loss over 12 months in free-living women assigned to four popular weight loss diets. The study tested for *absolute* effects of increasing intake of drinking water to ≥1 l/day, as well as *relative* effects of *replacing* caloric beverages with drinking water on weight loss. *Relative* effects on weight loss were expected for this sample, because drinking water *instead of* sweetened caloric beverages was associated with lower total energy intake in A TO Z participants (17). Multivariable models were used to explore whether change in beverage calories might mediate observed associations, and whether unsweetened or noncaloric beverages might be associated with comparable benefit.

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: *Dr Atkins New Diet Revolution* (18), *Enter the Zone, A Dietary Roadmap* (19), *The LEARN program for Weight Management*

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Received 30 November 2007; accepted 13 May 2008; published online 11 September 2008. doi:10.1038/oby.2008.409

2000 (ref. 20), or *Eat More Weigh Less by Dr Ornish* (21). The A TO Z study design and main findings are reported elsewhere (22). Study participants attended eight classes, once per week, to discuss a portion (~1/8) of their assigned diet book. The same Registered Dietitian, MS, RD, taught all diet classes. Participants were expected to have read the whole book by the end of the 2 months of classes. After the 2 months of classes, study participants were followed for 10 months. Dietary intake and body composition were recorded at baseline, 2, 6, and 12 months. After the 2-month visit, study participants were contacted by e-mail and telephone twice to collect data on self-rated dietary adherence and arrange follow-up visits.

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/day during the "Induction" phase (for up to 6 months) and intake of ≤50 g/day 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 55–60% of total energy intake with <10% of energy from saturated fat intake. The Ornish diet recommends lowering total fat intake to <10% of total energy intake. All four diets advise ~30 min of moderate physical activity on most days of the week.

Although not the focus of the A TO Z intervention, the Atkins, Zone, and LEARN books include advice about drinking water and other beverages. The Atkins book recommends ~2 l of drinking water per day: "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)" (18). The Zone book recommends three small meals and two snacks per day and "at least 8 oz of water or a sugar-free decaffeinated beverage with every meal or snack (p. 97)" (19). The Zone fluid recommendation is equivalent to approximately five 8 oz glasses or 1 l of water or sugar-free decaffeinated beverages per day. The LEARN book recommends at least 1 l of water per day: "As a rule of thumb, about four cups of water should be consumed for every 1,000 calories eaten (p. 121)" (20). The Ornish weight loss book used in this study did not provide specific beverage-intake guidelines. The present analysis takes advantage of intervention-related change in beverage intake to test for associations between drinking water and weight change.

Study sample

The A TO Z study included 311 premenopausal, overweight (BMI 27–40) women aged 25–50 years, who self-reported stable weight over the previous 2 months and were willing to accept random assignment to a weight loss diet. Selection criteria for the A TO Z study included plans to live in the area over the next year, availability to participate in the required evaluations and interventions, adequate English speaking, reading, and writing skills to participate in the study, and stable use of medications over the previous 3 months. Women were excluded if they self-reported uncontrolled hypertension, Type 1 or 2 diabetes, heart, renal, or liver disease, cancer or active neoplasms, uncontrolled hyperthyroidism, use of medications known to affect weight or energy expenditure, alcohol intake of three or more drinks per day or psychiatric care. Women who were postmenopausal, pregnant, lactating, or planning to become pregnant over the next year were also excluded.

To study the effect of increasing water intake to a level consistent with popular diet recommendations (e.g., ref. 18), this secondary analysis focused on healthy women who reported <1 l/day drinking water at baseline. Of the 311 women randomized to an intervention diet group, 302 self-reported good, very good, or excellent health. Of those with complete data on body weight, waist circumference, percent body fat (by dual-energy X-ray absorptiometry), and dietary intake at baseline ($n = 300$), 188 reported <1 l/day drinking water at baseline. After 2 months of diet classes, 173 women completed the 2-month diet and anthropometric assessments. At 6 months, dietary intake and body composition data were available for 162 (94%) and 157 (91%) women, respectively. At 12 months, data were available for 143 (83%) and 146 (84%) women, respectively. All study participants provided written informed consent, and the study was approved annually by the Stanford University Human Subjects Committee.

Body weight and composition

Body weight was measured in light clothing, to the nearest 0.1 kg using a calibrated clinical scale. Waist circumference was measured to the nearest millimeter. Fat mass was measured by dual-energy X-ray absorptiometry using the pencil-beam mode on a Hologic QDR-2000 instrument or the array mode on a Hologic QDR 4500 densitometer (Hologic, Waltham, MA). For each individual, repeat measurements were conducted using the same instrument.

Diet assessment

Dietary intake data were collected at 4-time points, at baseline, 2, 6, and 12 months. At each time point, three unannounced, telephone-administered, 24-h dietary recalls were collected on two nonconsecutive weekdays and one weekend day within three weeks of the clinic date when body weight was assessed. 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, University of Minnesota, Minneapolis, MN (versions 4.05.33 (2002), 4.06.34 (2003), and 5.0.35 (2004)). The interviewers were trained and certified by the Nutrition Coordinating Center in Minneapolis and were either Registered Dietitians or RD 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 8,000 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, sweetened caloric, unsweetened caloric, or noncaloric (nonwater) beverage, consistent with Nutrition Coordinating Center food–group codes available in the NDS and beverage groups of the Beverage Guidance panel (23). The drinking-water group included tap water, bottled spring water, mineral water, soda water, seltzer water, unsweetened sparkling, or carbonated waters. The sweetened caloric beverage group included soda pop, soft drinks, sweetened juices, flavored drinks, sweetened milks, sports drinks, sweetened coffees, sweetened teas, and sweetened cocoa. The unsweetened caloric beverage group included 100% fruit juices, vegetable juices, milks, and alcohol. The noncaloric beverage group included unsweetened plain teas and coffees, diet sodas, diet juices, and diet teas and coffees (<5 kcal or 21 kJ per serving).

Three-day mean daily intakes of drinking water, sweetened caloric, unsweetened caloric, and noncaloric beverages were calculated for each individual at each time point in absolute (ml) as well as relative units (% of total beverage intake). Three-day mean intakes of energy from food, food macronutrient (expressed as a % of energy), and water (g per 100 g of food) content were calculated.

Physical activity

At the baseline, 2, 6, and 12 month clinic visits, the Stanford Seven-Day Physical Activity Recall interview (24,25) was used to estimate activity levels over the previous week. An interviewer probed for the time spent sleeping, doing moderate, hard, and very hard physical activity, as well as the intensity and duration of each activity. Energy expenditure (kcal/kg/day) was estimated from the time spent in each activity multiplied by an average metabolic equivalent value.

Statistical analyses

All analyses were carried out using STATA statistical software (version 9.2, StataCorp, College Station, TX, 2003). Mixed models (xtmixed || id:) were used to estimate the effects of change in drinking water on change in body weight, waist circumference, and percent body fat over 12 months. Data from baseline, 2, 6, and 12 months were included in these models. Any missing data at 6 or 12 months were assumed missing at random or missing due to time-invariant individual characteristics.

To account for the observational nature of this study, three nested multivariable models were used to estimate the effects of drinking water controlling for potential confounding variables. Mixed models allow each participant to act as her own control. All models controlled for nontime-varying variables: age, race/ethnicity, baseline status, and diet treatment group. Model 1 included non-time-varying variables only. Model 2 added control for time-varying variables that covary with changes in beverage intake during weight loss diets: energy expenditure, energy intake from food, and food macronutrient and water composition. Model 3 added control for energy intake from beverages. Results from Models 2 and 3 were compared to determine whether change in beverage calories mediated or explained observed associations between drinking water and weight change.

Two sets of nested mixed models were evaluated. The first set of nested models estimated the average change in body weight, waist circumference, and percent body fat associated with an *absolute* increase of drinking water to ≥1 l per day over 12 months. The models were stratified by diet group to check whether associations might be attributable to individuals clustered within any particular intervention group.

A second set of nested models estimated the *relative* effects of *replacing* sweetened caloric beverages with drinking water. In addition to the covariates described above, these models included the total grams of beverages consumed and the intake of drinking water, unsweetened caloric and noncaloric beverages, expressed in relative terms (as % of beverages). Intake of sweetened caloric beverages was treated as the reference category, that is, the category of beverages to be replaced in these models because sweetened caloric beverages have been implicated in the obesity epidemic and are targeted for intervention (11,26). Holding constant the total grams of beverages consumed, the proportion of beverages from unsweetened caloric beverages, and the proportion of beverages from noncaloric beverages, a one-unit increase in drinking water in these models, imply a corresponding one-unit decrease in sweetened caloric beverages (the reference category). For a discussion of relative nutrient intake in multivariable models see Willett (27). As an increase in unsweetened caloric or noncaloric beverages in these models also implies an inverse shift in the reference category, the effects of unsweetened caloric and noncaloric alternatives to sweetened caloric beverages were also evaluated.

The models in this study combine information about within-person variation over time (fixed effects) and cross-sectional between-person variation (random effects). The fixed-effects portion of the model describes one regression line representing the population average of within-person change. The random effects portion allows the regression line to shift up or down for each individual (individual-specific intercept). The Hausman test was used to determine whether the within-person and between-person variation in water intake were similarly associated with variation in weight.

RESULTS

Change in beverage intake

Table 1 describes beverage intake for this study sample at baseline, 2, 6, and 12 months, stratified by intervention diet group. At baseline, all subjects reported <1 l of drinking water per day. Approximately half of the sample (51%) reported one or more sweetened caloric beverages per day (≥350 g/day). Sweetened caloric beverage intake ranged from 0 to 84% of beverages.

Over the 2 months of diet classes, intake of drinking water increased significantly in absolute terms for women in all diet

Table 1 Change in beverage intake over 12 months by diet group

	Total (n = 173)	Atkins (n = 42)	Zone (n = 47)	LEARN (n = 42)	Ornish (n = 42)
	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)
Drinking water (ml)					
Baseline	505 (30)	529 (63)	446 (55)	546 (57)	497 (67)
Change from baseline					
2 Months	+447 (43)*	+597 (89)*	+396 (77)*	+516 (80)*	+286 (95)*
6 Months	+287 (44)*	+377 (90)*	+280 (79)*	+322 (83)*	+167 (97)
12 Months	+288 (464)*	+251 (91)*	+407 (84)*	+312 (86)*	+194 (105)
Sweetened caloric beverages (ml)					
Baseline	414 (16)	348 (29)	456 (28)	395 (35)	455 (37)
Change from baseline					
2 Months	−201 (23)*	−253 (41)*	−250 (39)*	−141 (50)*	−153 (52)*
6 Months	−180 (23)*	−190 (41)*	−199 (40)*	−97 (52)	−233 (54)*
12 Months	−160 (24)*	−183 (441)*	−228 (42)*	−73 (53)	−149 (58)*
Unsweetened caloric beverages (ml)					
Baseline	275 (11)	237 (15)	250 (22)	383 (31)	236 (19)
Change from baseline					
2 Months	−106 (16)*	−172 (21)*	−83 (31)*	−139 (43)*	−34 (26)
6 Months	−96 (16)*	−128 (21)*	−96 (31)*	−97 (45)*	−63 (27)*
12 Months	−81 (17)*	−89 (21)*	−55 (33)	−168 (46)*	−14 (29)
Noncaloric beverages (ml)					
Baseline	444 (15)	460 (31)	395 (31)	452 (32)	473 (27)
Change from baseline					
2 Months	−54 (21)*	−27 (44)	+13 (43)	−116 (45)*	−92 (38)*
6 Months	−30 (22)	−30 (44)	+15 (44)	−103 (474)*	−9 (39)
12 Months	−3 (23)	−23 (45)	+47 (47)	−20 (48)	−15 (42)
Total beverage intake (ml)					
Baseline	1,637 (31)	1,575 (64)	1,548 (55)	1,776 (68)	1,661 (62)
Change from baseline					
2 Months	+87 (44)*	+145 (90)	+76 (78)	+120 (96)	+6 (87)
6 Months	−20 (45)	+28 (91)	−0.00 (80)	+26 (100)	−138 (89)
12 Months	45 (47)	−44 (91)	+171 (85)*	+50 (102)	+15 (97)

Drinking water: tap water, bottled spring water, mineral water, soda water, seltzer water, unsweetened sparkling water, carbonated water; sweetened caloric beverages: soda pop, soft drinks, sweetened juices, flavored drinks, sweetened milks, sports drinks, sweetened coffees, sweetened teas, sweetened cocoa; unsweetened caloric beverages: 100% fruit juices, vegetable juices, milks, alcohol; noncaloric beverages (<5 kcal/serving): unsweetened plain teas and coffees, diet sodas, diet juices, diet teas and coffees. At baseline and 2 months, dietary intake data were available for all 173 women. At 6 months, dietary intake data were available for 41 (98%), 44 (94%), 38 (90%), and 39 (93%) women in the Atkins, Zone, LEARN, and Ornish groups, respectively. At 12 months, diet data were available for 40 (95%), 37 (79%), 35 (83%), and 31 (74%) women, respectively. *P value <0.05 for change from baseline from unadjusted mixed models with drinking water, sweetened caloric beverage, unsweetened caloric beverage, noncaloric beverage, or total beverage intake as the outcome and time as the independent variable.

groups. Intake of drinking water remained significantly higher than baseline for the Atkins, Zone, and LEARN groups from 2 to 12 months, despite recidivism. Figure 1 shows the proportion of women in each diet group who reported ≥1 l/day drinking water at 2, 6, and 12 months.

Between baseline and 2 months, intake of drinking water increased in relative terms for women in all diet groups. As mean total beverage intake did not increase significantly in any diet group, drinking water replaced caloric beverages in the diet. Intake of drinking water increased from a mean (s.e.) of 30 (1)% of beverages at baseline to 51 (2)% of beverages at 2 months ($P < 0.05$), while intake of sweetened caloric beverages decreased from a mean (s.e.) of 26 (1)% of beverages at baseline to 14 (1)% of beverages at 2 months ($P < 0.05$). Change in relative beverage intake was normally distributed. The significant differences in beverage pattern relative to baseline remained at 6 and 12 months. Drinking water accounted for 45 (2)% and 46 (2)% of beverage intake at 6 and 12 months, while sweetened caloric beverages accounted for 17 (2)% and 16 (1)% of beverages, respectively.

Change in body weight and composition

Table 2 describes baseline body weight and composition and change in body weight and composition for the study sample, stratified by intervention diet group. Over the 2 months of diet classes, women in all diet groups lost weight. The average change in body weight over the 2-month period was approximately −3 kg. At 12 months, the average difference relative to baseline remained ~3 kg. Significant changes in waist circumference and percent body fat paralleled the changes in body weight.

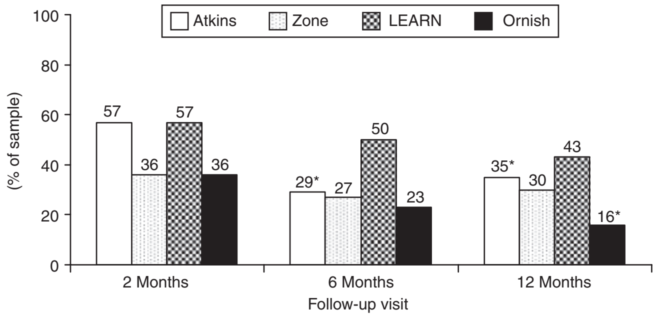

Figure 1 Proportion of the sample reporting ≥1 l/day drinking water at 2, 6, and 12 months by diet group. At baseline and 2 months, water intake data were available for all 173 women. All 173 women reported <1 l of drinking water per day at baseline. At 6 months, water intake data were available for 41, 44, 38, and 39 women in the Atkins, Zone, LEARN, and Ornish groups, respectively. At 12 months, water intake data were available for 40, 37, 35, and 31 women in each diet group, respectively. **P* value <0.05 for comparison with the corresponding value at 2 months using random effects logistic regression models (xtlogit command in stata).

Absolute increase in drinking water and change in body weight and composition

Table 3 presents the estimated difference in change in body weight, waist circumference and percent body fat associated with increasing intake of drinking water to ≥1 l/day vs. continued intake of <1 l/day. Over 12 months, the average increase in weight loss associated with drinking ≥1 l water per day was −2.3 (0.4) kg for the study sample (all diet groups combined). Drinking ≥1 l water per day was associated with significantly greater weight loss for women in all diet groups. The association remained after control for baseline characteristics (Model 1) and correlated changes in energy intake from food, food composition, and physical activity (Model 2). The association remained after additional control for change in energy from beverages (Model 3). For a given level of change in total energy intake, drinking >1 l/day was associated with significant benefit. The estimated fixed and random effects did not differ (Hausman *P* value >0.05). Parallel associations were observed between ≥1 l/day drinking water and waist circumference and body fat.

Relative increase in drinking water and change in body weight and composition

Table 4 presents the estimated changes in body weight, waist circumference, and percent body fat associated with *replacing* sweetened caloric beverages with drinking water, unsweetened caloric beverages, or noncaloric beverages.

Relative increases in drinking water were associated with weight loss. Adjusting for baseline characteristics, change in

Table 2 Change in body weight and composition over 12 months by diet group

	Total (n = 173)	Atkins (n = 42)	Zone (n = 47)	LEARN (n = 42)	Ornish (n = 42)
	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)	Mean (s.e.)
Body weight (kg)					
Baseline	85.5 (0.2)	86.5 (0.6)	85.0 (0.4)	83.1 (0.4)	87.2 (0.5)
Change from baseline					
2 Months	−0.3 (0.3)*	−5.0 (0.8)*	−2.5 (0.6)*	−2.9 (0.6)*	−3.0 (0.7)*
6 Months	−0.9 (0.4)*	−6.8 (0.8)*	−3.2 (0.6)*	−2.9 (0.6)*	−2.8 (0.7)*
12 Months	−0.1 (0.4)*	−5.7 (0.8)*	−2.5 (0.6)*	−2.1 (0.7)*	−2.0 (0.7)*
Waist circumference (cm)					
Baseline	95.2 (0.2)	96.7 (0.5)	95.6 (0.4)	92.8 (0.4)	95.8 (0.5)
Change from baseline					
2 Months	−3.8 (0.3)*	−5.7 (0.7)*	−3.3 (0.5)*	−3.6 (0.6)*	−2.7 (0.7)*
6 Months	−4.3 (0.3)*	−6.7 (0.7)*	−4.0 (0.6)*	−3.4 (0.6)*	−2.8 (0.7)*
12 Months	−4.2 (0.3)*	−6.4 (0.7)*	−3.9 (0.6)*	−3.5 (0.6)*	−2.9 (0.7)*
Body fat (%)					
Baseline	40.0 (0.2)	41.0 (0.4)	40.4 (0.3)	37.8 (0.2)	40.9 (0.3)
Change from baseline					
2 Months	−1.8 (0.2)*	−2.2 (0.6)*	−2.0 (0.4)*	−1.7 (0.3)*	−1.2 (0.5)*
6 Months	−2.7 (0.2)*	−4.0 (0.6)*	−2.7 (0.4)*	−2.0 (0.4)*	−1.8 (0.5)*
12 Months	−2.2 (0.2)*	−3.6 (0.6)*	−2.2 (0.4)*	−1.7 (0.4)*	−1.3 (0.5)*

**P* value <0.05 for change from baseline in unadjusted mixed models with body weight, waist circumference, or body fat as outcome and time as independent variable. For women in the Atkins, Zone, LEARN, and Ornish groups, respectively, data were available for 41, 42, 37, and 37 women at 6 months, and 40, 38, 35, and 33 women at 12 months.

Table 3 Regression coefficients from mixed models predicting the mean change in body weight and composition over 12 months associated with drinking ≥1 l water per day

	Total	Atkins	Zone	LEARN	Ornish
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
Body weight (kg)					
Model 1	−3.1 (0.4)*	−4.7 (0.8)*	−2.0 (0.6)*	−2.6 (0.6)*	−3.0 (0.7)*
Model 2	−2.3 (0.4)*	−1.9 (0.9)*	−1.2 (0.6)	−1.6 (0.6)*	−2.1 (0.8)*
Model 3	−2.2 (0.4)*	−1.6 (0.9)	−1.1 (0.6)	−1.7 (0.6)*	−1.9 (0.8)*
Waist circumference (cm)					
Model 1	−3.2 (0.3)*	−4.3 (0.8)*	−2.5 (0.6)*	−3.3 (0.6)*	−2.7 (0.8)*
Model 2	−2.3 (0.3)*	−1.5 (0.9)	−1.7 (0.6)*	−2.3 (0.6)*	−2.2 (0.8)*
Model 3	−2.1 (0.3)*	−1.2 (0.9)	−1.6 (0.6)*	−2.2 (0.6)*	−1.7 (0.8)*
Body fat (%)					
Model 1	−1.6 (0.2)*	−2.1 (0.6)*	−1.3 (0.5)*	−1.5 (0.3)*	−1.2 (0.5)*
Model 2	−1.1 (0.2)*	−0.4 (0.7)	−0.8 (0.5)	−1.0 (0.4)*	−0.8 (0.5)
Model 3	−1.0 (0.3)*	−0.2 (0.7)	−0.7 (0.5)	−1.0 (0.4)*	−0.6 (0.5)

Three nested mixed models were used to estimate the mean changes in body weight, waist circumference and percent body fat over 12 months associated with intake of ≥1 l/day drinking water, adjusting for various covariates. All models included data from all four time points. Models for the whole sample included 173 women. The Atkins, Zone, LEARN, and Ornish group-specific models included 42, 47, 42, and 42 women, respectively. Model 1 controlled for age, race/ethnicity, baseline status, and diet treatment group. Model 2 controlled for all the variables in Model 1 as well as energy expenditure, energy intake from food, and food macronutrient and water composition. Model 3 controlled for energy intake from beverages in addition to all of the variables in Model 2. **P* value <0.05.
Coef., coefficient.

Table 4 Regression coefficients from mixed models estimating the effects of replacing sweetened caloric beverages with drinking water, unsweetened caloric-, or noncaloric beverages on change in body weight and composition, adjusting for covariates

	Model 1	Model 2	Model 3
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
Body weight (kg)			
Drinking water (% of beverages)	−0.051 (0.010)*	−0.030 (0.011)*	−0.010 (0.012)
Sweetened caloric beverages (% of beverages)	REF	REF	REF
Unsweetened caloric beverages (% of beverages)	−0.011 (0.017)	−0.010 (0.017)	−0.024 (0.017)
Noncaloric beverages (% of beverages)	−0.029 (0.011)*	−0.020 (0.012)	0.000 (0.013)
Total beverage intake (l)	−0.75 (0.31)*	−0.84 (0.31)*	−1.22 (0.33)*
Waist circumference (cm)			
Drinking water (% of beverages)	−0.059 (0.010)*	−0.034 (0.010)*	−0.014 (0.011)
Sweetened caloric beverages (% of beverages)	REF	REF	REF
Unsweetened caloric beverages (% of beverages)	0.010 (0.017)	−0.009 (0.016)	−0.023 (0.016)
Noncaloric beverages (% of beverages)	−0.031 (0.011)*	−0.021 (0.011)	−0.002 (0.012)
Total beverage intake (l)	−0.55 (0.29)	−0.62 (0.29)*	−0.96 (0.30)*
Body fat (%)			
Drinking water (% of beverages)	−0.028 (0.007)*	−0.019 (0.007)*	−0.004 (0.008)
Sweetened caloric beverages (% of beverages)	REF	REF	REF
Unsweetened caloric beverages (% of beverages)	0.02 (0.012)	−0.004 (0.011)	−0.014 (0.012)
Noncaloric beverages (% of beverages)	−0.014 (0.008)	−0.011 (0.008)	0.003 (0.009)
Total beverage intake (l)	−0.41 (0.21)	−0.32 (0.21)	−0.59 (0.22)*

Changes in body weight, waist circumference and percent body fat were respectively evaluated in three nested mixed models. All models included data from 173 women from all four time points. Model 1 controlled for age, race/ethnicity, baseline status, and diet treatment group. Model 2 controlled for all the variables in Model 1 as well as energy expenditure, energy intake from food, and food macronutrient and water composition. Model 3 controlled for energy intake from beverages in addition to all of the variables in Model 2. Beverage-intake variables were expressed in relative terms (% of beverages) in all models. All models treated sweetened caloric beverages as the reference category (REF). Holding constant the total beverage volume and proportion of beverages from unsweetened- and noncaloric beverages, a unit increase in drinking water implies a corresponding unit decrease in sweetened caloric beverages. **P* value <0.05.
Coef., coefficient.

food intake, and physical activity (Model 2 in **Table 4**), each one percentage unit of sweetened caloric beverages replaced with drinking water was associated with a 0.030 (0.011) kg weight loss, a 0.034 (0.010) cm decrease in waist circumference, and a 0.019 (0.007) decrease in percent body fat (Model 2). For 40 percentage units of sweetened caloric beverages (% of beverages) replaced with drinking water, the predicted mean decreases in body weight, waist circumference, and percent body fat would be 1.2 kg, 1.4 cm, and 0.8%. For 80 percentage units replaced with water, the predicted mean decreases would be 2.4 kg, 2.8 cm, and 1.6%, respectively.

To determine whether change in beverage calories might explain effects of beverage change on change in body weight and composition, Model 3 in **Table 4** added control for change in beverage calories. After additional control for change in beverage calories, the effects of replacing sweetened caloric beverages with drinking water disappeared. The estimated fixed and random effects of relative increases in drinking water on weight loss did not differ (Hausman *P* value >0.05).

Unsweetened caloric and noncaloric alternatives to sweetened caloric beverages were associated with less benefit than drinking water. Relative increases in unsweetened caloric beverages (e.g., milk or juice) were not associated with weight loss. Relative increases in noncaloric beverages (e.g., "diet" drinks) were associated with a 30% smaller effect (0.020 kg vs. 0.030 kg weight loss). For 80 percentage units of sweetened caloric beverages replaced with a noncaloric beverage other than water the predicted mean decrease in weight would be 1.6 kg instead of 2.4 kg.

The models in **Table 4** include total beverage volume as an independent predictor. Controlling for beverage composition, an increase in beverage volume was significantly associated with weight loss, independent of all covariates, including beverage calories.

DISCUSSION

The results of this study suggest that drinking water may promote weight loss for overweight women following weight loss diets. Absolute and relative increases in drinking water were associated with decreases in body weight, waist circumference, and percent body fat in overweight women assigned to four popular weight loss diets. The associations were independent of diet group, food composition, physical activity, and sociodemographic variables. The associations were only partially attributable to change in calories from beverages. Intake of unsweetened and noncaloric (diet) beverages was not associated with comparable benefit.

In this study, an absolute increase in drinking water to ≥1 l/day was associated with ~2 kg or 5 lbs weight loss over 12 months. A 2 kg weight loss is consistent with experimental data showing that 500 ml drinking water increases energy expenditure by 100 kJ (1). Over 12 months, 1 l/day drinking water would increase annual energy expenditure by ~73 MJ (17,400 calories) or 2 kg of fat.

The observed effects of drinking water in this study were robust. Weight loss attributable to drinking water was independent of sociodemographic variables, baseline status, changes in food composition, energy intake from food, and physical activity. It was observed in women following four diets of markedly different macronutrient composition (22). It was observed with three different indicators of weight loss: loss of body weight, change in waist circumference, and change in percent body fat by dual-energy X-ray absorptiometry.

The results of this study are consistent with expectation that drinking *water instead of caloric beverages* may promote weight loss by eliminating beverage calories and lowering total energy intake. Change in beverage calories explained the observed associations between relative increases in drinking water and weight loss. In the Stanford A TO Z cohort, drinking water instead of caloric beverages was associated with a significant decrease in beverage calories and total energy intake that was maintained over time (17). The results suggest that short-term (<1 day) effects of drinking water on energy intake (5–16) translate into weight loss over time. Considering that sweetened caloric beverages account for ~10% of total energy intake for US adults (28), recommendations to alter beverage intake might have significant public health impact.

The results of this study suggest that other variables besides beverage calories and total energy intake may mediate effects of drinking water on weight loss. Although beverage calories explained observed *relative* effects of drinking water, they did not wholly explain the *absolute* effects of drinking water. Intake of ≥1 l/day was associated with weight loss independent of beverage calories. Noncaloric beverages were not comparable to drinking water, despite similar calorie content. Noncaloric beverages may differ from water in terms of content (e.g., sweeteners), palatability and/or psychosocial food pairing or behavioral cues. Controlling for beverage pattern and beverage calories, the total beverage volume was independently associated with weight loss.

This study is limited with respect to inferences about the residual effects of drinking water after control for energy intake. Although drinking water may promote weight loss by increasing energy expenditure and/or rates of lipolysis (1–4), variables necessary to explore these pathways were not assessed in the A TO Z study. Further work is needed to determine whether postprandial resting energy expenditure and/or macronutrient metabolism mediate beneficial effects of drinking water on weight loss.

The Stanford A TO Z study was not designed to test specific effects of drinking water on weight loss. Aside from unmeasured intermediates, biomarkers of water intake, such as water turnover or hydration status, were not assessed. As the study sample was not randomized to drinking-water treatments, the observed associations may be confounded. Consumers of drinking water may differ in multiple ways from nonconsumers of drinking water (29). They may have been more motivated to diet, more restrained eaters or less depressed than nonconsumers. Changes in micronutrient intake were not controlled in this study. Control for physical activity was based on a self-reported measure. The observed associations may not generalize to other population groups or conditions.

Although limited with respect to causal inference, the data in this study are uniquely suited to address questions about beverage intake and weight change. The Stanford A TO Z study induced marked change in beverage intake and followed study participants over 12 months. The 12 month follow-up far exceeded the 8-week periods reported in other studies. Data from four time points allowed control for key time varying and time-invariant risk factors for weight loss in multivariable models that account for missing data. Unlike other studies of beverage intake and weight change, which only report absolute intake of particular beverages (30,31), the A TO Z study assessed total beverage intake and food intake in detail, using state-of-the-art diet interviewing methods. The available data allowed study of absolute and relative intake of drinking water and other beverages, while controlling for food intake and composition.

No other studies in the literature evaluate long-term effects of drinking water on change in body weight or composition. Other studies of beverage change and weight change do not specify drinking water as a test or control beverage (30,31). Although drinking water before or with a meal does not reduce *food* intake (7,8,32–37), it should not be dismissed as a potential risk factor for weight loss without consideration of its effects on *total* energy intake from food *and beverages*. Adverse effects of caloric beverages may be confounded by a correlated loss of protective effects of drinking water. Randomized trials are needed to confirm and characterize absolute and relative effects of drinking water on weight loss.

ACKNOWLEDGMENTS

We gratefully acknowledge the careful work of the study dietitians, Rise Cherin, Andrea Vaccarella, Noel Segali, and Gretchen George. J.D.S. was responsible for all aspects of this secondary analysis, study question, data analysis, and manuscript preparation. C.D.G. conducted the Stanford A TO Z Study. C.D.G., B.M.P., and F.C. contributed to the data analysis and manuscript preparation. Funding for the A TO Z study was provided by National Institutes of Health grant R21 AT001098, by a grant from the Community Foundation of Southeastern Michigan, and by Human Health Service Grant M01-RR00070, General Clinical Research Centers, National Center for Research Resources, National Institutes of Health. Funding for this analysis was provided by an unrestricted grant from Nestle Waters.

DISCLOSURE

Three of the authors (J.D.S., B.M.P., C.D.G.) have no conflicts of interest. F.C. is an employee of Nestle's Water.

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