Intakes of plain water, moisture in foods and beverages, and total water in the adult US population—nutritional, meal pattern, and body weight correlates: National Health and Nutrition Examination Surveys 1999–2006[1–3]

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ABSTRACT

Background: There is a surprising paucity of studies that have systematically examined the correlates of water intake in the US population.

Objective: The objective was to examine the association of contributors of water intake with dietary characteristics, meal consumption, and body weight in the US population.

Design: We used 24-h dietary recall data from the National Health and Nutrition Examination Survey (NHANES) 1999–2004 (n = 12,283) and the NHANES 2005–2006 (n = 4112) to examine the independent association of intakes of plain water, beverage moisture, food moisture, and total water with sociodemographic factors, dietary characteristics (energy, nutrients, diet quality, and energy density), and meal patterns (number of eating episodes, mention of breakfast or snack) by using multiple regression methods.

Results: In 2005–2006, American adults reported consuming 3.18 L of total water within the previous 24 h (in 1999–2004, estimated total water intake was 3.35 L), with plain water and beverages contributing 33% and 48% of the total, respectively. Plain water intake was unrelated to the intake of energy and body mass index but was positively related to dietary fiber and inversely related to beverages, sugars, and the energy density of foods; these associations were in the opposite direction for beverage moisture intake. Total water intake was inversely related to energy from fat and energy density but positively related to dietary fiber, caffeine, alcohol, and diet quality. The number of eating episodes predicted higher beverage and food moisture and total water intakes. A higher body mass index predicted higher intakes of beverage moisture and total water.

Conclusion: Various contributors of total water intake differed in their association with dietary characteristics and body weight in the adult US population. *Am J Clin Nutr* 2009;90:655–63.

INTRODUCTION

Water, an essential nutrient, has well-recognized metabolic and functional sequelae with even short-term deprivation; adverse consequences from excessive water intake also are a possibility (1). The panel on Dietary Reference Intakes for Electrolytes and Water in its 2004 report established the first reference intake (ie, for Adequate Intake) for total water on the basis of self-reported dietary data from the Third National Health and Nutrition Examination Survey (1988–1994) (1). In its report, the expert panel also identified several gaps in the published information about water intake, including the association of water intake profiles with diet and meal patterns (1).

As reviewed by Valtin (2), despite popular beliefs about the importance of drinking 8 cups of water a day and the supposed benefits of water intake in body weight management, there is a surprising paucity of systematic studies in this area. A number of individual characteristics—eg, age, dietary sodium and protein intake, and physical activity—are known to affect water requirements (1), yet little is known about whether self-reported water intake is related to variations in these factors. Given the interest in understanding the association (if any) of water intake with a variety of health outcomes, including various cancers and coronary heart disease (1), understanding correlates of water intake in a free-living population can help in the identification of population subgroups that may benefit from interventions.

Although a number of studies have examined the nutritional correlates of the consumption of beverages, especially sweetened beverages (3–7), similar information in relation to plain water or total water intake is scarce (8–10). In an attempt to fill in these gaps in knowledge, we used recent nationally representative data to examine: *1*) the sociodemographic and lifestyle correlates of intakes of plain water, moisture in foods and beverages, and total water and *2*) the association of plain water and moisture intake with reported dietary characteristics and meal patterns of US adults.

SUBJECTS AND METHODS

We used data from the continuous National Health and Nutrition Examination Surveys (c-NHANES) 1999–2000, 2001–

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2002, 2003–2004, and 2005–2006, which were conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (11–14). Each survey was a stratified, multistage, national probability sample of the civilian noninstitutionalized population of the United States (11–14). The survey procedures consisted of a household interview and a health examination of the subject in the mobile examination center. Anthropometric measurements (height, weight, etc) and an in-person interview to collect 24-h dietary recall were obtained in the mobile examination center. All surveys used a computer-assisted dietary interview for obtaining a multiple-pass dietary recall. Beginning with the NHANES 2002, the dietary recall was collected by using the automated multiple-pass method, which was developed and validated by the US Department of Agriculture (12). Survey response rates for the individuals examined at the mobile examination center for the c-NHANES 1999–2000, 2001–2002, 2003–2004, and 2005–2006 were 76%, 80%, 76%, and 77%, respectively (11–14).

Plain water and moisture intake

In the 1999–2004 surveys, respondents were asked "How much plain water did you drink yesterday?" after collection of the 24-h dietary recall (11–13). Information about the intake of plain carbonated water was obtained as part of the 24-h recall in 1999–2001 (11, 12); in 2002–2004, this information was obtained by asking a separate question after the recall (12, 13). However, the water intake (plain or carbonated) information in the 2005–2006 survey was collected by integrating water questions within the 24-h recall rather than after recall (14). (The reasons for changes in the methodology for collection of plain water intake data beginning in the 2005–2006 survey are not described in the documentation.) Because of these methodologic differences in how plain water information was collected beginning with the 2005–2006 survey, we combine data for 1999–2004, but present 2005–2006 data separately.

The public release data for the c-NHANES 1999–2006 include variables for plain water and moisture content of all foods and beverages reported in the recall. For each 24-h recall, we examined 4 different types of water variables for this study: *1*) intake of plain water (defined by the NCHS to include tap water, water from a water cooler or drinking fountain, spring water, and noncarbonated bottled water); *2*) moisture in foods reported in the 24-h recall; *3*) moisture in beverages reported in the 24-h recall; and *4*) total water intake (the sum of plain water and moisture in foods and beverages). We considered all types of liquid milk, shakes, fruit or vegetable juices, juice drinks, carbonated and noncarbonated sweetened or unsweetened drinks, coffee, tea, hot chocolate, all alcoholic drinks, and carbonated water as beverages. For the 1999–2004 surveys, we created the total moisture variable as described above; for the 2005–2006 survey, we used the equivalent variable created by the NCHS and available in the public release data set. In all surveys, we included plain carbonated water in the beverages category.

Analytic sample

c-NHANES 1999–2004

All respondents aged ≥20 y with a dietary recall considered complete and reliable by the NCHS were eligible for inclusion in this study (*n* = 13,431). We excluded recalls of pregnant and lactating women (*n* = 843), recalls from proxies (*n* = 270), reports of 0 calories (*n* = 2), and recalls of those missing information on water intake in the previous 24 h (*n* = 33) from the eligible sample. With these exclusions, the final analytic sample included 12,283 men and women.

c-NHANES 2005–2006

In this survey, there were 4520 respondents aged ≥20 y with a reliable recall. After exclusions for pregnancy/lactating state (*n* = 353), recall from proxies (*n* = 54), and reports of 0 calories (*n* = 1), the final analytic sample included 4112 men and women.

Dietary and meal pattern variables examined

We examined the self-reported 24-h intakes of dietary energy, fat, carbohydrate, total sugars, added sugars, as well as dietary variables identified as determinants of water requirements in the Institute of Medicine report (protein, fiber, sodium, caffeine, and 24-h alcohol) in relation to all water and moisture intake variables operationalized in this study. The "added sugars" variable was created by merging the NHANES 1999–2004 data with the MyPyramid Equivalents Database of the US Department of Agriculture (15, 16). We also assessed the energy density of foods only (plain water or beverages reported in the recall were not included in this estimation) as kilocalories per gram of reported foods. By using the methods described previously (17), we created variables to assess meal patterns; these variables included the number of eating episodes, mention of breakfast and any snack in the recall, and the percentage of recalled intake reportedly consumed after 1700 h. In addition, we assessed the association of all water intake variables with a simple measure of overall diet quality, which assessed the diet for variety among food groups (mention of at least one food from each of the major 5 food groups—dairy, fruit, vegetable, grain, and meat or alternative in the recall). We have previously used this simple indicator of diet quality in relation to dietary nutrient intake and mortality as outcome (18, 19). Finally, where available (NHANES 1999–2002), we examined the association of water intake variables with the Healthy Eating Index (20). The Healthy Eating Index is a complex measure of diet quality created by the US Department of Agriculture to assess concurrence with the Dietary Guidelines for Americans (21).

Analytic methods

We used multiple linear regression methods to compute covariate adjusted means (ie, predicted margins) of all water intake variables separately for the c-NHANES 1999–2004 and 2005–2006. The covariates included sex, age, race-ethnicity, body mass index, poverty-income ratio, years of education, smoking status, day of diet recall, leisure-time physical activity, average daily physical activity, any self-reported chronic disease, and survey wave (in analyses that included combined c-NHANES 1999–2004). The adjusted means were computed from covariate adjusted regression models by direct standardization of the means to the distribution of the covariates for the combined US populations represented by the weighted NHANES samples (22). We examined the association of dietary, meal pattern, and body-weight-related variables with each contributor of water intake as a dependent variable by adding the relevant nutritional or meal pattern variable to the multiple linear regression models. For dietary variables such as energy or nutrient intake, we present the regression coefficient and its SE to reflect the predicted change in reported water and moisture intakes for a given change in energy or nutrient intakes as independent variables. Similarly, for associations of meal patterns with water and moisture intake, we present the associated regression coefficient, its SE, and the P value. We present these associations by using regression models with and without energy adjustment. Low-energy reporting has been reported as a problem in national surveys including the NHANES (23). Low-energy reporting may affect the ability to detect associations of dietary intake exposures with weight-related outcomes. We examined low-energy reporting in the present study by computing the ratio of reported energy intake to the estimated basal energy expenditure by using the sex-specific equation recommended by the Dietary Reference Intake committee (24). For weight-related outcomes, we present estimates of association that include the ratio of energy intake to basal energy expenditure as an independent variable. Respondents with complete information on all covariates were included in multivariate regression models.

All statistical analyses were performed by using SAS (version 9.1; SAS Institute, Cary, NC) and software designed for the analysis of complex survey data (SAS-callable SUDAAN, version 9) (25). SUDAAN software computes variance estimates that are corrected for the multistage, stratified, cluster probability design of complex surveys. Sample weights provided by the NCHS to account for differential probabilities of selection, noncoverage, and nonresponse were used in all analyses to obtain point estimates. All reported P values for testing for significant association from regression models used the F-statistic with a Satterthwaite correction for the df (26).

RESULTS

This article presents results from the c-NHANES 2005–2006 and notes the different associations between the combined 1999–2004 surveys and the 2005–2006 survey. Results from the c-NHANES 1999–2004 are available under "Supplemental data" in the online supplement.

Sociodemographic and lifestyle correlates of contributors of water intake in 2005–2006

Men reported higher adjusted amounts of moisture in beverages, foods, and total water (but not plain water) ($P < 0.0001$) (**Table 1**). The reported plain water intakes did not differ among race-ethnic groups; however, race-ethnicity was a significant correlate of reported intakes of moisture in foods and beverages and total water. The self-reported plain water, beverage moisture, and total water declined with increasing age ($P \leq 0.003$). Higher education was associated with higher self-reported plain water and food moisture intakes ($P \leq 0.003$). Current smokers had a lower intake of moisture in foods ($P = 0.0002$), but a higher intake of beverages and total water ($P \leq 0.0003$). Any leisure-time physical activity was associated with higher intakes of plain and total water; higher average activity on a typical day was a correlate of a higher amount of moisture from beverages and total water. Body mass index (BMI) showed positive associations with beverage moisture and total water ($P \leq 0.01$). Reported food moisture was higher on weekdays than on weekends ($P = 0.006$).

In the c-NHANES 1999–2004, higher plain water intake was reported by men, those with a higher BMI, and in association with higher average daily physical activity (*see* Supplement Table 1 under "Supplemental data" in the online issue). Years of education were unrelated to plain water intake.

Association of contributors of water intake with intake of dietary nutrients and other dietary components reported in the 24-h recall in 2005–2006

The plain water intake was positively associated with the reported intake of moisture in foods but inversely associated with beverage moisture intake ($P < 0.0001$) (**Table 2**). However, the intakes of moisture in beverages and foods were unrelated ($P > 0.05$). Dietary energy intake was unrelated to plain water intake, but was a positive correlate of the moisture content of foods, beverages, and total water ($P < 0.0001$). Dietary protein (as percentage of energy) was unrelated to total water and related positively to plain water and food moisture intake but inversely related to beverage moisture ($P < 0.0001$). Intakes of dietary fat and carbohydrate (as percentage of energy) were inversely related to total water intake ($P \leq 0.007$). Energy density (kilocalories per gram) of foods was an inverse correlate of plain water, food moisture, and total water, but a positive correlate of beverage moisture ($P < 0.0001$). Dietary fiber and sodium intakes were positively associated with all components of water intake. The moisture content of beverages and total water were positive correlates of 24-h caffeine and alcohol intakes. Total sugars were inversely related to plain water intake ($P = 0.04$), but positively related to moisture in foods and beverages and total water ($P \leq 0.0001$). With adjustment for energy intake, the associations of these dietary variables with components of fluid intake were generally attenuated, and sodium and total sugar were not related to total water intake.

In the combined data from 1999 to 2004, the following association differed from those mentioned above: food moisture was unrelated to dietary fat, carbohydrate, and caffeine intake (Supplemenetal Table 2 under "Supplemental data" in the online issue). Intake of added sugar was inversely related to plain water, but positively related to other water variables.

Meal pattern correlates of contributors of water intake reported in the 24-h recall in 2005–2006

The number and amount of nonbeverage foods were positively associated with all water variables except beverage moisture (**Table 3**). The reported number of eating episodes, mention of breakfast or a snack, and the percentage of 24-h energy consumed after 1700 were not related to plain water intake ($P > 0.05$). The number of eating episodes and mention of a snack were positive correlates of moisture in foods and beverages and total water. Those who reported breakfast or a snack reported higher moisture content of foods ($P < 0.0001$). Mention of all 5 food groups in the recall was associated with higher intake of moisture in foods and total water ($P \leq 0.0003$), but not with plain water or beverage moisture. With energy adjustment, most

TABLE 1

Independent correlates of contributors of water intake among Americans aged ≥20 y: continuous National Health and Nutrition Examination Survey (c-NHANES) 2005–2006[1]

	Plain water	Moisture in beverages	Moisture in foods	Total water
	g	*g*	*g*	*g*
All (unadjusted) *n* = 4112	1057 ± 52	1537 ± 43	578 ± 11	3172 ± 66
All (*n* = 3878; adjusted for covariates)[2]	1061 ± 51	1539 ± 43	580 ± 12	3179 ± 68
Sex				
Males	1044 ± 48	1783 ± 55	641 ± 16	3467 ± 79
Females	1079 ± 67	1298 ± 35	520 ± 13	2897 ± 72
P value	0.5	<0.0001	<0.0001	<0.0001
Race-ethnicity				
Non-Hispanic white	1090 ± 62	1657 ± 46	581 ± 12	3327 ± 80
Non-Hispanic black	979 ± 64	1139 ± 40	518 ± 17	2636 ± 86
Mexican-American	1009 ± 54	1272 ± 66	597 ± 19	2877 ± 107
Other	963 ± 78	1267 ± 99	644 ± 28	2873 ± 126
P value	0.2	<0.0001	0.004	<0.0001
Age				
20–39 y	1181 ± 83	1555 ± 68	566 ± 14	3300 ± 118
40–59 y	1104 ± 63	1693 ± 53	593 ± 19	3390 ± 70
≥60 y	809 ± 41	1262 ± 48	580 ± 12	2650 ± 65
P value	0.003	<0.0001	0.3	<0.0001
Years of education				
<12	900 ± 57	1619 ± 105	548 ± 16	3066 ± 133
12	980 ± 70	1549 ± 52	538 ± 15	3067 ± 83
>12	1142 ± 51	1512 ± 39	607 ± 12	3260 ± 56
P value	0.003	0.4	0.0002	0.04
Poverty-income ratio				
<1	953 ± 88	1504 ± 86	600 ± 19	3057 ± 99
1–<2	1024 ± 73	1488 ± 41	598 ± 15	3111 ± 98
≥2	1088 ± 55	1558 ± 54	572 ± 14	3217 ± 73
P value	0.3	0.5	0.2	0.2
Smoking status				
Never smoked	1121 ± 56	1327 ± 53	598 ± 14	3045 ± 70
Former smoker	1028 ± 50	1528 ± 53	611 ± 13	3167 ± 100
Current smoker	976 ± 83	1972 ± 55	513 ± 15	3460 ± 85
P value	0.09	<0.0001	0.0002	0.0003
Any leisure physical activity lasting ≥10 min over the previous month?				
Yes	1112 ± 50	1543 ± 44	587 ± 13	3242 ± 72
No	933 ± 64	1528 ± 58	561 ± 16	3021 ± 69
P value	0.001	0.8	0.2	0.0003
Average activity on a usual day?				
Mostly sitting	998 ± 64	1487 ± 65	584 ± 17	3068 ± 58
Mostly standing	1060 ± 61	1471 ± 37	579 ± 8	3110 ± 74
Carry light loads or climb hills	1100 ± 93	1680 ± 87	577 ± 19	3357 ± 109
Heavy work or carry heavy loads	1142 ± 110	1733 ± 55	582 ± 29	3457 ± 123
P value	0.6	0.01	1.0	0.004
Body mass index[3]				
<25 kg/m^2	989 ± 55	1398 ± 33	581 ± 19	2967 ± 78
25–<30 kg/m^2	1041 ± 65	1589 ± 62	561 ± 13	3190 ± 85
≥30 kg/m^2	1152 ± 86	1625 ± 58	598 ± 10	3375 ± 89
P value	0.2	0.002	0.07	0.001
Day of recalled dietary intake				
Monday–Thursday	1068 ± 61	1507 ± 59	599 ± 17	3173 ± 78
Friday–Sunday	1053 ± 49	1581 ± 36	554 ± 8	3187 ± 68
P value	0.7	0.2	0.006	0.8
Self-reported chronic disease?				
Yes	1126 ± 75	1538 ± 55	583 ± 15	3245 ± 83
No	1026 ± 43	1539 ± 44	578 ± 10	3143 ± 67
P value	0.08	1.0	0.7	0.1

[1] All values are adjusted means ± SEs unless otherwise indicated. The level of significance for each variable from multiple linear regressions in the presence of other variables in the model is based on an *F*-statistic that includes the Satterthwaite correction for the df. The multiple linear regression models included all covariates listed above, with plain water listed above, food and beverage moisture, or total water as a continuous dependent.

[2] After exclusion of those missing information on any covariate (*n* = 3878).

[3] The models also included the ratio of reported energy intake to estimated basal energy expenditure as an independent variable.

of these associations were attenuated and remained significant only for the number of eating episodes.

In the combined data from the c-NHANES 1999–2004, the number and amount of nonbeverage foods showed a positive association with beverage moisture, the percentage of energy reported after 1700 h was a positive correlate of food moisture, and mention of 5 food groups in the recall was a positive correlate of plain water intake (*see* Supplemental Table 3 under "Supplemental data" in the online issue). The Healthy Eating Index was unrelated to plain water intake but predicted higher food moisture and total water intake.

Association of self-reported body-weight-related variables with contributors of water intake in the 24-h recall in 2005–2006

Self-perception of body weight was a weak independent correlate of beverage moisture intake (**Table 4**). A subject's

TABLE 2

Association of different contributors of water intake with energy, macronutrients, and other dietary constituents reported in a 24-h recall by adult Americans: continuous National Health and Nutrition Examination Survey (c-NHANES) 2005–2006[1]

Independent variable	Plain water	Moisture in beverages	Moisture in foods	Total water
	g	*g*	*g*	*g*
Plain water (100 g)	—	−14.5 ± 1.7	4.0 ± 0.6	—
P value	—	<0.0001	<0.0001	—
Moisture in beverages (100 g)	−18.4 ± 2	—	1.0 ± 0.8	—
P value	<0.0001	—	0.25	—
Energy (100 kcal)	4.4 ± 3.3	44.1 ± 3.7	16.5 ± 0.8	65.0 ± 3.2
P value	0.2	<0.0001	<0.0001	<0.0001
Protein (5% energy)	84 ± 19	−133 ± 29	52 ± 6	3 ± 35
P value	0.0005	0.0004	<0.0001	0.9
Fat (5% energy)	13 ± 13	−72 ± 17	8 ± 4	−51 ± 16
P value	0.3	0.0006	0.05	0.007
Carbohydrate (5% energy)	−24 ± 10	−12 ± 12	−5 ± 2	−41 ± 11
P value	0.03	0.3	0.04	0.002
Energy density of foods only[2] (kcal/g)	−245 ± 37	264 ± 35	−311 ± 8	−291 ± 51
P value	<0.0001	<0.0001	<0.0001	<0.0001
Fiber (5 g)	78 ± 12	37 ± 15	100 ± 4	216 ± 19
P value	<0.0001	0.03	<0.0001	<0.0001
Energy-adjusted fiber (5 g)	94 ± 14	−108 ± 18	81 ± 4	66 ± 22
P value	<0.0001	<0.0001	<0.0001	0.008
Sodium (100 mg)	4 ± 1.5	11 ± 2.5	10 ± 0.3	25 ± 2.2
P value	0.02	0.0005	<0.0001	<0.0001
Energy-adjusted sodium (100 mg)	5 ± 2.4	−13 ± 2.2	8 ± 0.6	−1.0 ± 0.3
P value	0.07	<0.0001	<0.0001	0.7
Caffeine (50 mg)	−16 ± 8	129 ± 9	3.5 ± 1.6	116 ± 14
P value	0.07	<0.0001	0.04	<0.0001
Energy-adjusted caffeine (50 mg)	−18 ± 8	120 ± 8	−0.5 ± 1.5	102 ± 10
P value	0.05	<0.0001	0.7	<0.0001
24-h alcohol intake (5 g)	−0.6 ± 2	73 ± 7	1.5 ± 1.2	71 ± 8
P value	0.8	<0.0001	0.2	<0.0001
Energy-adjusted 24-h alcohol intake (5 g)	−3 ± 3	59 ± 7	−9 ± 1	47 ± 8
P value	0.4	<0.0001	<0.0001	<0.0001
Total sugars (10 g)	−7 ± 3	41 ± 3	9 ± 1.3	43 ± 5
P value	0.04	<0.0001	<0.0001	<0.0001
Energy-adjusted total sugars (10 g)	−16 ± 3	16 ± 5	−4 ± 1	−4 ± 5
P value	0.0001	0.007	0.004	0.4

[1] Values are βs ± SEs associated with units of measurement given in parentheses for each independent variable. For example, for every 100-kcal increase in energy intake, plain water intake increased by 4 g, moisture in beverages increased by 44 g, food-only moisture increased by 16 g, and total water intake increased by 65 g. The multiple linear regression models included sex, age (20–39, 40–59, ≥60 y), race-ethnicity (non-Hispanic white, non-Hispanic black, Mexican-American, or other), poverty-income ratio (<1, 1–<2, or ≥2), education (<12, 12, or >12 y), smoking status (never smoked, current smoker, or former smoker), chronic disease (yes or no self-reported diabetes, heart disease, high blood pressure, and stroke), day of recall (Monday–Thursday or Friday–Sunday), any self-reported leisure-time physical activity lasting ≥10 min in the previous 30 d (yes or no), average daily level of physical activity (mostly sit, mostly stand and walk, carry light loads, or carry heavy loads), and BMI (in kg/m^2; <25, 25–29.9, or ≥30) as independent variables with each water contributor as the dependent variable. Energy-adjusted models included energy intake (kcal) as a continuous variable. n = 3878 for respondents with complete covariate information. *P* values for testing the level of significance for each variable from multiple linear regressions in the presence of other variables in the model are based on an *F*-statistic that includes the Satterthwaite correction for the df.

[2] With the exclusion of plain water and all beverages.

TABLE 3

Association of contributors of water intake with meal patterns reported in a 24-h recall: continuous National Health and Nutrition Examination Survey (c-NHANES) 2005–2006[1]

	Plain water	Moisture in beverages	Moisture in foods	Total water
	g	*g*	*g*	*g*
No. of unique nonbeverage foods reported in the 24-h recall	18.0 ± 4.8	10.5 ± 7.1	29.8 ± 1.0	58.4 ± 8.1
P value	0.002	0.1	<0.0001	<0.0001
Amount of all nonbeverage foods in the 24-h recall (g)	0.36 ± 0.06	0.16 ± 0.08	0.69 ± 0.009	1.21 ± 0.07
P value	<0.0001	0.06	<0.0001	<0.0001
No. of eating episodes reported in the 24-h recall	5.2 ± 14.1	163 ± 16	41 ± 4.9	209 ± 20
P value	0.7	<0.0001	<0.0001	<0.0001
No. of eating episodes reported in the 24-h recall (energy adjusted)	−2 ± 16	98 ± 17	14 ± 3	109 ± 19
P value	0.9	<0.0001	0.0002	<0.0001
Mentioned breakfast in the 24-h recall	51.6 ± 74.1	21.2 ± 63.3	78 ± 24	151 ± 123
P value	0.5	0.7	0.005	0.2
Mentioned breakfast in the 24-h recall (energy adjusted)	39 ± 71	−108 ± 68	31 ± 19	−39 ± 109
P value	0.6	0.1	0.1	0.7
Mentioned a snack in the 24-h recall	−27 ± 66	233 ± 46	86 ± 20	293 ± 98
P value	0.7	0.0001	0.0007	0.009
Mentioned a snack in the 24-h recall (energy adjusted)	−0.6 ± 0.5	76 ± 38	1.8 ± 1.0	60 ± 77
P value	0.5	0.06	0.1	0.4
Percentage of energy from evening food intake in the 24-h recall	1.4 ± 1.1	−1.9 ± 1.1	0.8 ± 0.4	0.3 ± 1.5
P value	0.2	0.1	0.05	0.9
Mentioned 5 food groups in the 24-h recall	115 ± 70	75 ± 45	141 ± 10	332 ± 72
P value	0.1	0.1	<0.0001	0.0003
Mentioned 5 food groups in the 24-h recall (energy adjusted)	104 ± 73	−67 ± 44	92 ± 13	130 ± 72
P value	0.2	0.1	<0.0001	0.09

[1] All values are βs ± SEs. The multiple linear regression models included sex, age (20–39, 40–59, or ≥60 y), race-ethnicity (non-Hispanic white, non-Hispanic black, Mexican-American, or other), poverty-income ratio (<1, 1–<2, or ≥2), education (<12, 12, or >12 y), smoking status (never smoked, current smoker, or former smoker), chronic disease (yes or no self-reported diabetes, heart disease, high blood pressure, and stroke), day of recall (Monday–Thursday or Friday–Sunday), any self-reported leisure-time physical activity lasting ≥10 min in the previous 30 d (yes or no), average daily level of physical activity (mostly sit, mostly stand and walk, carry light loads, or carry heavy loads), and BMI (in kg/m^2; <25, 25–29.9, or ≥30) as independent variables with each water contributor as the dependent variable. Energy-adjusted models included energy intake (kcal) as a continuous variable. n = 3878 for respondents with complete covariate information. *P* values for testing the level of significance for each variable from multiple linear regressions in the presence of other variables in the model are based on an *F*-statistic that includes the Satterthwaite correction for the df.

desire for weighing more, less, or the same was a weak correlate of differences in intakes of plain water, beverage moisture, and total water ($P \leq 0.03$).

In the c-NHANES 1999–2004, with a few exceptions, nearly all components of fluid intake were significant correlates of body-weight-related variables (*see* Supplemental Table 4 under "Supplemental data" in the online issue). Those who considered themselves as overweight, had attempted weight loss in the previous year, and expressed a desire to weigh less reported the highest beverage moisture and total water intakes relative to other categories of these variables.

DISCUSSION

In 2005–2006, of the 3.18 L (13.4 cups) total water (the sum of plain water and moisture in foods and beverages) reported by adult Americans over the previous 24 h, ≈33% was consumed as plain water, 48% as beverages, and the remaining 18% as food. The Dietary Reference Intake report on Water and Electrolytes also estimated that 81% of the total water reported in the NHANES III was contributed by plain water and beverages (1). Relative to 2005–2006, the mean estimates of total water intake in the c-NHANES 1999–2004 were higher by ≈177 mL. This difference is largely because of a higher mean plain water intake reported in 1999–2004. In 1999–2004, although the combined intakes of plain water and beverages equaled ≈82%, the plain water comprised a higher proportion of the total (≈37%). The extent to which these differences reflect different methods for collecting plain water intake data in these surveys (integrated in the 24-h recall in 2005–2006 and a separate question after recall in 1999–2004) is not known.

Our results suggest that population characteristics (age, education, and leisure physical activity) that usually correlate with better dietary outcomes were related to plain water intake in the

TABLE 4
Independent association of contributors of water intake with body-weight-related variables among Americans aged ≥20 y: continuous National Health and Nutrition Examination Survey (c-NHANES) 2005–2006[1]

	Plain water	Moisture in beverages	Moisture in foods	Total water
	g	*g*	*g*	*g*
Consider self: (*n* = 3876)				
Overweight	1028 ± 48	1596 ± 48	573 ± 15	3196 ± 63
Underweight	1079 ± 148	1381 ± 84	576 ± 37	3035 ± 181
Normal weight	1113 ± 75	1467 ± 54	591 ± 13	3171 ± 98
P value	0.4	0.04	0.5	0.6
Tried to lose weight in the previous year (*n* = 3876)				
Yes	1043 ± 48	1574 ± 66	587 ± 14	3204 ± 77
No	1080 ± 73	1505 ± 36	573 ± 12	3157 ± 87
P value	0.6	0.3	0.3	0.6
Would like to weigh (*n* = 3878)				
More	1176 ± 99	1294 ± 86	597 ± 39	3067 ± 116
Less	992 ± 50	1584 ± 46	567 ± 14	3142 ± 62
Same	1206 ± 83	1486 ± 56	609 ± 13	3300 ± 101
P value	0.02	0.02	0.1	0.03

[1] All values are adjusted means ± SEs. The multiple linear regression models included sex, age (20–39, 40–59, or ≥60 y), race-ethnicity (non-Hispanic white, non-Hispanic black, Mexican-American, or other), poverty-income ratio (<1, 1–<2, or ≥2), education (<12, 12, or >12 y), smoking status (never smoked, current smoker, or former smoker), chronic disease (yes or no self-reported diabetes, heart disease, high blood pressure, and stroke), day of recall (Monday–Thursday or Friday–Sunday), any self-reported leisure-time physical activity lasting ≥10 min in the previous 30 d (yes, no), average daily level of physical activity (mostly sit, mostly stand and walk, carry light loads, or carry heavy loads), BMI (in kg/m^2; <25, 25–29.9, or ≥30), and the ratio of reported energy intake to estimated basal energy expenditure as independent variables with each water contributor as the dependent variable. *n* refers to respondents with complete covariate information. *P* values for testing the level of significance of each variable from multiple linear regressions in the presence of other variables in the model are based on an *F*-statistic that includes the Satterthwaite correction for the df.

expected direction. Relative to other smoking categories, current smokers had the highest total water intake, largely because of higher beverage moisture, given that the plain water and food water intakes among smokers were lower. De Castro and Taylor (10) have also reported higher beverage intake in smokers. Notably, both leisure and average daily physical activity were associated with total water intake; however, the association reflected higher plain water intake by those reporting any leisure activity, but higher beverage intake by those reporting higher average daily activity. Because fruits and vegetables are dietary constituents with the highest water content, higher food moisture intake (noted in association with higher education, never/former smokers, and recalls on weekdays) may be interpreted as indicating diets with likely contributions of these desirable food groups. Arguably, higher food moisture intake may also reflect higher food quantity intake; however, the observed associations remained unchanged by adjustment for energy intake (related to amount of food). (Energy-adjusted estimates are not shown in Table 1 but are available from the authors.)

The inverse association of plain water intake with beverage moisture but positive association with moisture in foods suggests some substitution effect of plain water intake on beverage consumption and possibly higher fruit and vegetable intake. Although these associations may be expected to affect energy intake, we found plain water and energy intake to be unrelated in all surveys. Popkin et al (8) have reported lower energy intake in association with plain water intake. We caution that these comparisons are problematic because the analysis in the above study used a different definition of water and compared plain water reporters and nonreporters, and the reported findings appear to be unadjusted for confounding due to factors related to energy and water intake. Nevertheless, the associations of the intake of plain water with dietary fiber intake (positive), energy density of foods, and total and added sugars (inverse) do suggest different dietary selections in relation to plain water intake. Other dietary characteristics examined in this study (intakes of protein, dietary fiber, sodium, caffeine, and alcohol) were discussed in the Institute of Medicine report as possible determinants of water requirements (1). All of these variables (except dietary protein intake and sodium intakes) showed positive associations with total water intake with and without adjustment for energy intake in our study. To our knowledge, there is no published information on these associations to allow comparisons.

Surprisingly, few studies have examined the association of dietary sodium intake with components of water intake (27, 28). A recent study has suggested that the association of sodium intake with the intake of sweetened beverages may be a mechanism for inducing positive energy balance with consequent weight gain in children (29). However, in the present study, with adjustment for energy intake—although sodium intake remained a positive correlate of food moisture—the association with beverage moisture became inverse, and the overall association with total water intake was no longer significant. These observations suggest that sodium and total water intake association may largely reflect the association of food quantity and sodium intake.

The associations of reported meal patterns (number of eating episodes, mention of breakfast or snack in the recall, and extent of energy consumed in the evening) with plain water intake were generally unremarkable. Other significant associations of meal patterns with food, beverage, and total water were not observed after adjustment for energy intake.

Although the possibility and extent of water-induced thermogenesis and its potential importance in weight management remains controversial (30, 31), consumption of plain water is promoted in most sensible weight management plans. In the present study, beverage moisture and total water intake increased with increasing BMI in all surveys; however, the association of plain water intake with BMI and weight-related variables (history of attempted weight loss in the previous year and desire to weigh less) were noted in 1999–2004 but not in 2005–2006. Whether these differences reflect different methods for collection of plain water information in 1999–2004 compared with 2005–2006 is not known.

Increasing consumption of sweetened beverages has been suggested as a potential contributor to higher energy intake with consequent weight gain in the US population (5, 32). Moreover, there is evidence that the satiating effect of beverages is lower than that of solid foods with possibly poor regulation of the resulting liquid energy intake (33). As expected, we observed an inverse association of food moisture with the energy density of foods (34). However, our results indicate that plain water and beverage consumption had a divergent association with the energy density of foods reported in the recall with plain water predicting lower energy density and beverage intake predicting higher energy density of foods, which suggests that another mechanism for higher energy intakes (beverage consumption) operates in association with high-energy density diets.

Because of within-person variability in food intake, a single 24-h dietary recall is not suitable for determining usual intake distributions (24); therefore, we do not attempt to describe usual intake distributions of various contributors of daily water intake. We present population means and standard errors (for which a 24-h recall provides an unbiased estimate) for the various water variables and, when we examine associations, they are within the context of the 24-h recall. Measurement error, especially the misreporting of energy intake, is an acknowledged problem in all dietary assessment methods (24). Although the use of automated multiple-pass methods to obtain the 24-h dietary recall is an improvement over older methods of collecting recalls, underreporting of energy intake, especially in association with body weight, remains a problem (35). In a study of the sources of reporting errors in the automated multiple-pass method, beverages and vegetables were the largest contributors to energy reporting bias in highly educated lean men (36). Although our analyses were adjusted for subject characteristics (such as body weight, level of education, and income) with known associations with reporting errors, we acknowledge that it is likely that beverage moisture, food moisture, and total water intake may be underestimated in our study. Finally, although our study provides estimates of various contributors to total water intake adjusted for multiple covariates, the NHANES public release data do not include information on geographic location and season of exam. We expect geographic location and season of exam to be highly correlated in the NHANES data. We note that an analysis of the Continuing Survey of Food Intakes by Individuals 1994–1996 data found relatively little seasonal variation in water intake among adults (37).

In conclusion, our results suggest that contributors of total water vary with respect to the sociodemographic and lifestyle characteristics of the US population and in association with selected dietary characteristics. Given the divergent associations of plain water compared with beverage moisture intakes with dietary energy, fiber, sugars, and energy density, the study provides evidence to encourage water intake over beverages and attests to the need to examine contributors of water along with total water intake.

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REFERENCES

1. Institute of Medicine. Food and Nutrition Board. Panel on Dietary Reference Intakes for Electrolytes and Water: dietary reference intakes for water, potassium, sodium, chloride, and sulfate. Washington, DC: National Academy Press, 2004.
2. Valtin H. "Drink at least eight glasses of water a day." Really? Is there scientific evidence for "8 × 8"? Am J Physiol Regul Integr Comp Physiol 2002;283:R993–1004.
3. Harnack L, Stang J, Story M. Soft drink consumption among US children and adolescents: nutritional consequences. J Am Diet Assoc 1999; 99:436–41.
4. Storey ML, Forshee RA, Anderson PA. Beverage consumption in the US population. J Am Diet Assoc 2006;106:1992–2000.
5. 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.
6. Bleich SN, Wang YC, Wang Y, Gortmaker SL. Increasing consumption of sugar-sweetened beverages among US adults: 1988–1994 to 1999–2004. Am J Clin Nutr 2009;89:372–81.
7. Wang YC, Bleich SN, Gortmaker SL. Increasing caloric contribution from sugar-sweetened beverages and 100% fruit juices among US children and adolescents, 1988–2004. Pediatrics 2008;121:e1604–14.
8. Popkin BM, Barclay DV, Nielson SJ. Water and food consumption patterns of U.S. adults from 1999 to 2001. Obes Res 2005;13:2146–52.
9. Fulgoni VL 3rd. Limitations of data on fluid intake. J Am Coll Nutr 2007;26:588S–91S.
10. de Castro JM, Taylor T. Smoking status relationships with the food and fluid intakes of free-living humans. Nutrition 2008;24:109–19.
11. Centers for Disease Control and Prevention. National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey (NHANES). Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention. NHANES 1999–2000. Available from: http://www.cdc.gov/nchs/about/major/nhanes/nhanes99_00.htm (cited July 2008).
12. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey (NHANES). Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention. NHANES 2001–2002. Available from: http://www.cdc.gov/nchs/about/major/nhanes/nhanes01-02.htm (cited July 2008).
13. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey (NHANES). Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention. NHANES 2003–2004. Available from: http://www.cdc.gov/nchs/about/major/nhanes/nhanes2003–2004/nhanes03_04.htm (cited July 2008).
14. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey (NHANES). Hyattsville, MD: US Department of Health and Human Services, Centers for Disease Control and Prevention.

NHANES 2005–2006. Available from: http://www.cdc.gov/nchs/about/major/nhanes/nhanes2005-2006/nhanes05_06.htm (cited August 2008).
15. Friday JE, Bowman SA. MyPyramid Equivalents Database for USDA Survey Food Codes, 1994–2002 Version 1.0. Beltsville, MD: USDA, Agricultural Research Service, Beltsville Human Nutrition Research Center, Community Nutrition Research Group. Available from: http://www.barc.usda.gov/bhnrc/fsrg (cited 3 October 2008).
16. Bowman SA, Friday JE, Moshfegh A. MyPyramid Equivalents Database for USDA Survey Foods, 2003–2004, Version 2.0. Food Surveys Research Group. Beltsville Human Nutrition Research Center, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD. Available from: http://www.ars.usda.gov/ba/bhnrc/fsrg (cited 3 October 2008).
17. Kant AK, Graubard BI. Secular trends in patterns of self-reported food consumption of adult Americans: NHANES 1971–1975 to NHANES 1999–2002. Am J Clin Nutr 2006;84:1215–23.
18. Kant AK, Block G, Schatzkin A, Ziegler RG, Nestle M. Dietary diversity in the US population, NHANES II, 1976–1980. J Am Diet Assoc 1991;91:1526–31.
19. Kant AK, Schatzkin A, Harris TB, Ziegler RG, Block G. Dietary diversity and subsequent mortality in the First National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. Am J Clin Nutr 1993;57:434–40.
20. Archived Files for the original Healthy Eating Index. Available from: http://www.cnpp.usda.gov/HealthyEatingIndex-Archive.htm (cited 3 October 2008).
21. Kennedy ET, Ohls J, Carlson S, Fleming K. The Healthy Eating Index: design and applications. J Am Diet Assoc 1995;95:1103–8.
22. Graubard BI, Korn E. Predictive margins with survey data. Biometrics 1999;55:652–9.
23. Food and Nutrition Board. Institute of Medicine. Dietary Reference Intakes: Applications in dietary assessments. Washington, DC: National Academy Press, 2000.
24. Institute of Medicine. Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: National Academy Press, 2002/2005.
25. Research Triangle Institute. SUDAAN. Release 9.0. Research Triangle Park, NC: Research Triangle Institute, 2008.
26. Thomas DR, Rao JNK. Small-sample comparisons of level and power for simple goodness-of-fit statistics under cluster sampling. J Am Stat Assoc 1987;82:630–6.
27. Luft FC, Fineberg NS, Sloan RS, Hunt JN. The effect of dietary sodium and protein on urine volume and water intake. J Lab Clin Med 1983;101:605–10.
28. He FJ, Markandu ND, Sagnella GA, MacGregor GA. Effect of salt intake on renal excretion of water in humans. Hypertension 2001;38:317–20.
29. He FJ, Marrero NM, MacGregor GA. Salt intake is related to soft drink consumption in children and adolescents: a link to obesity? Hypertension 2008;51:629–34.
30. Boschmann M, Steiniger J, Hille U, et al. Water-induced thermogenesis. J Clin Endocrinol Metab 2003;88:6015–9.
31. Brown CM, Dulloo AG, Montani JP. Water-induced thermogenesis reconsidered: the effects of osmolality and water temperature on energy expenditure after drinking. J Clin Endocrinol Metab 2006;91:3598–602.
32. Schulze MB, Manson JE, Ludwig DS, et al. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. JAMA 2004;292:927–34.
33. 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.
34. Kant AK, Graubard BI. Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight. Int J Obes (Lond) 2005;29:950–6.
35. Moshfegh AJ, Rhodes DG, Baer DJ, et al. The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. Am J Clin Nutr 2008;88:324–32.
36. Rumpler WV, Kramer M, Rhodes DG, Moshfegh AJ, Paul DR. Identifying sources of reporting error using measured food intake. Eur J Clin Nutr 2008;62:544–52.
37. Heller KE, Sohn W, Burt BA, Eklund SA. Water consumption in the United States in 1994–96 and implications for water fluoridation policy. J Public Health Dent 1999;59:3–11 (Published erratum appeared in: J Public Health Dent 2000;60:4).