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Plain water consumption in relation to energy intake and diet quality among US adults, 2005–2012

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Abstract

Objective: The present study examined plain water consumption in relation to energy intake and diet quality among US adults.
Methods: A nationally representative sample of 18 311 adults aged ≥18 years, from the National Health and Nutrition Examination Survey 2005–2012, was analysed. The first-difference estimator approach addressed confounding bias from time-invariant unobservables (e.g. eating habits, taste preferences) by using within-individual variations in diet and plain water consumption between two nonconsecutive 24-h dietary recalls.
Results: One percentage point increase in the proportion of daily plain water in total dietary water consumption was associated with a reduction in mean (95% confidence interval) daily total energy intake of 8.58 (7.87–9.29) kcal, energy intake from sugar-sweetened beverages of 1.43 (1.27–1.59) kcal, energy intake from discretionary foods of 0.88 (0.44–1.32) kcal, total fat intake of 0.21 (0.17–0.25) g, saturated fat intake of 0.07 (0.06–0.09) g, sugar intake of 0.74 (0.67–0.82) g, sodium intake of 9.80 (8.20–11.39) mg and cholesterol intake of 0.88 (0.64–1.13) g. The effects of plain water intake on diet were similar across race/ethnicity, education attainment, income level and body weight status, whereas they were larger among males and young/middle-aged adults than among females and older adults, respectively. Daily overall diet quality measured by the Healthy Eating Index-2010 was not found to be associated with the proportion of daily plain water in total dietary water consumption.
Conclusions: Promoting plain water intake could be a useful public health strategy for reducing energy and targeted nutrient consumption in US adults, which warrants confirmation in future controlled interventions.

Introduction

Adequate hydration is essential to body function [(1)]. Drinking plain water, such as tap or bottled water, delivers adequate hydration without adding calories [(2)]. Plain water intake has been linked to reduced energy consumption and improved body weight management [(3–6)]. Potential mechanisms include, but may not be limited to, plain water intake in substitution for caloric beverage consumption [(7)], and satiety from plain water consumption in coping with feelings of hunger and desire to eat [(8)].

The *Dietary Guidelines for Americans, 2010* recommended sweetened beverages to be 'replaced with water and unsweetened beverages' as a way to reduce added sugar consumption [(9)]. In September 2014, and again in October 2015, a group of researchers, scientists, nutritionists, clinicians and public health professionals sent a 'Best of Science' letter to the US Department of Agriculture (USDA) and US Department of Health and Human Services Secretaries [(10)]. The letter reviewed scientific evidence on the importance of plain water intake for obesity prevention and for health in general, and urged the Dietary Guidelines Advisory Committee to adopt strong language in the upcoming *Dietary Guidelines for Americans, 2015* encouraging Americans to drink plain water, and the USDA to consider modifying the MyPlate graphic (http://www.choosemyplate.gov) to include water.

Previous research on the relationship between plain water consumption and energy/nutrient intake mainly consists of small-scale interventions [11–14], which, despite an experimental study design, often lack generalisability to the national population. Population-level epidemiological studies on the role of plain water consumption in the daily diet remain limited. To our knowledge, five studies to date have examined plain water consumption on a national scale, all using data from the National Health and Nutrition Examination Survey (NHANES). Popkin *et al.* [15] performed a cluster analysis on water and food consumption patterns based on data from the NHANES 1999–2001 wave. Using data from the NHANES 2003–3004 wave, Wang *et al.* [16] examined the impact of plain water and caloric beverage consumption on daily energy intake among children and adolescents. Kant *et al.* [17] explored various contributors of daily total dietary water consumption and their correlations with nutrient intake and body weight using data from the NHANES 2005–2006 wave. Drewnowski *et al.* [18,19] documented plain water and beverage consumption patterns among US children and adults using data from the NHANES 2005–2010 waves; however, they did not assess the relationship between water consumption and daily energy/nutrient intake or diet quality. Except for Wang *et al.* [16], all of the above studies adopted a cross-sectional study design, which makes the findings susceptible to the risk of confounding bias as a result of a possible failure in controlling for between-individual differences in characteristics such as food or taste preferences. Morover, population heterogeneity has been understudied: demographic and socio-economic subgroups may differ in the relationship between plain water consumption and energy/nutrient intake because of various dissimilarities in genetic and sociobehavioural factors such as metabolism, dietary habits, health attitudes, nutrition knowledge and affordability [20]. Documenting these population heterogeneities can be essential in designing targeted policy interventions.

Based on previous literature, the present study examined the relationship between plain water consumption and energy/nutrient intake among US adults using data from a nationally representative survey. It serves as an early attempt to study the role of plain water consumption in daily diet using a panel data approach, which employed within-individual variations in diet between the two non-consecutive 24-h dietary recall days and thus addressed the confounding issue as a result of unobservable individual characteristics such as taste preferences. We hypothesised that the proportion of daily plain water in total dietary water consumption was inversely associated with total energy intake, energy intake from sweetened beverages and discretionary foods, and the consumption of total fat, saturated fat, sugar, sodium and cholesterol, whereas it was positively associated with overall diet quality. We examined the relationship between plain water consumption and energy/nutrient intake in the overall US adult population, as well as by sex, race/ethnicity, age group, education attainment, income level and body weight status.

Materials and methods

Survey setting and participants

The NHANES is a programme of studies conducted by the National Center for Health Statistics (NCHS) aiming to assess the health and nutritional status of children and adults. The programme began in the early 1960s and has periodically conducted separate surveys focusing on different population groups or health topics. From 1999 onward, NHANES has been conducted continuously in 2-year cycles and has a changing focus on a variety of health and nutrition measurements. A multistage probability sampling design is used to select participants representative of the civilian, non-institutionalised US population. Certain population subgroups are oversampled to increase the reliability and precision of health status indicator estimates for these groups.

The present study used individual-level data from the NHANES 2005–2006, 2007–2008, 2009–2010 and 2011–2012 waves. These waves were chosen because the collection of data on tap and bottled water consumption as a beverage only started in 2005 as part of the 24-h dietary recall, whereas, in previous waves, such information was assessed via questionnaire after the 24-h dietary recall was completed. Nevertheless, sensitivity analyses incorporating data from the NHANES 2003–2004 wave produced results almost identical to those based on data from later waves.

Dietary interview

Except for the NHANES 1999–2000 wave where all respondents were asked to complete a single 24-h dietary recall, all subsequent waves incorporated two dietary recalls, with the first collected in-person and the second by telephone, 3–10 days later. In both interviews, each food or beverage item and corresponding quantity consumed by a respondent from midnight to midnight on the day before the interview was recorded. The in-person dietary recall (day 1) was conducted by trained dietary interviewers in the Mobile Examination Center (MEC) with a standard set of measuring guides. These tools aimed to help the participant accurately report the volume and dimensions of the food/beverage items consumed. Upon completion of the in-person interview, participants were provided measuring cups, spoons, a ruler and a food model booklet, which contained two-dimensional drawings of the various measuring guides available in the MEC, for use when reporting dietary intake during the telephone interview (day 2). Following the dietary interview, the energy and nutrient contents of each reported food and/or beverage item were systematically coded with the USDA Food and Nutrient Database for Dietary Studies (http://www.ars.usda.gov/Services/docs.htm?docid=12089). Access restrictions apply to the day 2 dietary recall data collected in the NHANES 2001–2002 wave, whereas dietary data for both recall days are released to the public for all subsequent waves.

Among the 19 245 US adults aged ≥18 years who participated in both 24-h dietary recalls in the NHANES 2005–2012 waves, 934 (4.9%) who were pregnant, lactating and/or on a special weight-loss diet at the time of interview were excluded, resulting in a final sample size of 18 311 participants.

Water consumption

In accordance with Drewnowski *et al.* [18,19], plain water consumption includes the intake of plain tap water, water from a drinking fountain, water from a water cooler, bottled water and spring water. Total dietary water consumption includes the intake of plain water and water from other beverages and foods. For example, unsweetened black tea, herbal tea and coffee do not count as sources of plain water, although their water content is included in the calculation of total dietary water consumption. We calculated an individual's percentage of plain water in total dietary water consumption on a dietary recall day.

Sugar-sweetened beverage consumption

Sugar-sweetened beverages (SSBs) include sodas, fruit drinks, energy drinks, sports drinks and sweetened bottled waters, consistent with definitions reported by the Centers for Disease Control and Prevention and the National Cancer Institute (NCI) [21,22]. Milk (plain or flavoured) and 100% fruit juice were excluded. In NHANES 2011–2012 wave, SSBs consist of 48 reported beverage items. The number of reported items in the SSB category differed only slightly across survey waves.

Discretionary food consumption

The discretionary food category identifies energy-dense, nutrient-poor food products that do not belong to the main food groups or do not necessarily contain essential nutrients that the human body requires but may add diversity [23]. Foods in this category may be consumed 'sometimes in small amounts by those who are physically active, but are not a necessary part of the diet' [23]. In accordance with Bleich *et al.* [24] and An [25], specific food items in the discretionary food category include cookies, pies, ice cream, confectionery, chocolate, other desserts (e.g. custards, puddings, mousse, gelatin dessert), sweet rolls, waffles, cakes, pastries (e.g., crepes, cream puffs, strudels, croissants, muffins, sweet breads), biscuits, hush puppies, chips, popcorn, pretzels, party mixes, and fries. In the NHANES 2011–2012 wave, the discretionary food category consists of 661 reported food items. The number of reported items in the discretionary food category differed only slightly across survey waves.

Energy intake

In the NHANES dietary interview data, energy derived from each consumed food or beverage item was recorded based on the quantity of food/beverage reported and the corresponding energy content. We calculated total energy intake, energy intake from SSBs and energy intake from discretionary foods for each survey participant on a dietary recall day.

Diet quality

The Healthy Eating Index (HEI)-2010 was developed by the USDA as a measure of dietary quality in accordance with the *Dietary Guidelines for Americans, 2010* [9,26]. It consists of 12 components: total fruit, whole fruit, total vegetables, greens and beans, whole grains, diary, total protein foods, seafood and plant proteins, fatty acids, refined grains, sodium, and empty calories (calories from solid fats, alcohol and added sugars). With a maximum score of 100, a higher HEI-2010 score reflects closer adherence to the Federal dietary guidelines. We calculated each the HEI-2010 score for each NHANES participant on either 24-h dietary recall day using the MyPyramid Equivalents Database (http://www.cnpp.usda.gov/mypyramid) and in accordance with the procedures established by the USDA and NCI [27,28].

Other outcome variables

Other outcome variables included daily quantities consumed of total fat (g), saturated fat (g), sugar (g), sodium (mg) and cholesterol (mg). *Dietary Guidelines for Americans, 2010* recommended a significant reduction in the consumption of those nutrients in both children and adults [9].

Individual characteristics

The individual characteristics reported for US adults aged ≥18 years were: sex, age (stratified into two age groups: 18–64 years and ≥65 years), race/ethnicity (non-Hispanic white, non-Hispanic African American, non-Hispanic other race or multi-race, and Hispanic), education (high school and below, and college and above), household income [income to poverty ratio (IPR) < 130%, 130% ≤ IPR < 300%, and PIR ≥ 300%] and body weight status. Body height and weight for participants was measured using a stadiometer and digital scale in the MEC. Body mass index (BMI) is defined by weight (kg) divided by the square of height (m^2). Body weight status was classified as underweight (BMI < 18.5 kg m^{-2}), normal weight (18.5 kg m^{-2} ≤ BMI < 25 kg m^{-2}), overweight (25 kg m^{-2} ≤ BMI < 30 kg m^{-2}) and obese (BMI ≥ 30 kg m^{-2}) based on the international classification of adult BMI values [29].

Statistical analysis

The first-difference estimator approach was used based on data from the day 1 and day 2 dietary interviews that provided two observations per person. The outcome (i.e. daily total energy intake, daily energy intake from SSBs, daily energy intake from discretionary foods, daily quantities consumed of total fat, saturated fat, sugar, sodium and cholesterol, and daily overall diet quality) of participant i on day t (t = 1,2) is denoted by y_{it}. We let vector X_i represent the set of variables that vary by participant (e.g. sex and race/ethnicity) but remain constant within-participant between the two dietary interviews. Given the short recall time interval of 3–10 days, X_i includes individual characteristics that vary only in the longer term, such as age, education attainment, income level, body weight, etc. Continuous variable $pwater_{it}$ (ranging from 0 to 100) denotes the percentage of plain water in total dietary water consumption by participant i on day t. Indicator variable we_{it} denotes whether day t was a weekend (Friday, Saturday or Sunday).

A pooled cross-sectional setup (a conventional regression that treats repeated measures within each study subject as independent observations) specifies the outcome y_{it} as a function of an unobservable term that varies by participant α_i, observable variables that vary by participant X_i, observable variables that vary within-participant between the two dietary interviews $pwater_{it}$ and we_{it}, and an independently-distributed unobservable disturbance term ε_{it}.

$$y_{it} = \mu X_i + \beta_1 pwater_{it} + \beta_2 we_{it} + \alpha_i + \varepsilon_{it} \quad (1)$$

As a result of the presence of the unobservable term α_i (e.g. eating habits, taste preferences), estimating Equation (1) by controlling for the observables X_i only is prone to omitted variable bias. The first-difference estimator eliminates the bias by taking the difference between the 2 days of data within each participant, so that α_i and μX_i that are common within-participant are removed.

$$\begin{aligned} y_{i1} - y_{i2} = &\beta_1(pwater_{i1} - pwater_{i2}) + \beta_2(we_{i1} - we_{i2}) \\ &+ (\varepsilon_{i1} - \varepsilon_{i2}) \end{aligned} \quad (2)$$

Equation (2) was estimated for the overall adult sample and subsamples stratified by sex, race/ethnicity (non-Hispanic other race/multi-race excluded because of insufficient sample size), age group, education attainment, income level and body weight status (underweight excluded because of insufficient sample size).

Based on the Equation (2) estimates, we simulated an increase in daily plain water consumption by one, two and three US cups at the same time as holding daily total dietary water consumption constant. Given an average daily plain water intake of 999 g and daily total dietary water intake of 2934 g, an increase in daily plain water intake by one, two and three US cups approximately translates into an increase in the proportion of daily plain water in total dietary water consumption of 8%, 16% and 24% points, respectively.

The NHANES 2005–2012 multiyear complex survey design was accounted for in both the descriptive statistics and the regression analyses. All statistical procedures were performed in STATA, version 14.1 SE (StataCorp, College Station, TX, USA).

The NHANES was approved by the NCHS Research Ethics Review Board. The present study used de-identified public data from NHANES and was deemed exempt by the University of Illinois at Urbana-Champaign Institutional Review Board.

Results

Table 1 reports individual characteristics of adult study participants in the NHANES 2005–2012 waves. On average, participants consumed 999 g (4.22 US cups) of plain water (tap and bottled water) on a daily basis, accounting for slightly above 30% of daily total dietary water consumption from all beverages and foods combined. Daily total energy intake averaged 2157 kcal, with an energy intake from SSBs of 125 kcal and from discretionary foods of 432 kcal. Daily intakes of total fat, saturated fat, sugar, sodium and cholesterol averaged 80 g, 26 g, 117 g, 3503 mg and 283 mg, respectively. Daily overall diet quality measured by the HEI-2010 scored 49 among participants. Almost two-thirds of participants were either overweight or obese, with less than one-third in the normal weight range.

Table 2 reports estimated changes in daily diet associated with a change in the proportion of daily plain water in total dietary water consumption based on the first-difference estimator. One percentage point increase in the proportion of daily plain water in total dietary water consumption was associated with a reduction in mean (95% confidence interval) daily total energy intake of 8.58 (7.87–9.29) kcal, energy intake from sugar-sweetened beverages of 1.43 (1.27–1.59) kcal, energy intake from discretionary foods of 0.88 (0.44–1.32) kcal, total fat intake of 0.21 (0.17–0.25) g, saturated fat intake of 0.07 (0.06–0.09) g, sugar intake of 0.74 (0.67–0.82) g, sodium intake of 9.80 (8.20–11.39) mg and cholesterol intake of 0.88 (0.64–1.13) g. By contrast, daily overall diet quality measured by the HEI-2010 was not found to be associated with the proportion of daily plain water in total dietary water consumption.

A reduction in the daily consumption of total energy, energy from SSBs, total fat, saturated fat, sugar, sodium and cholesterol associated with an increase in the proportion of daily plain water in total dietary water consumption was present among all population subgroups under investigation. The only exception was energy intake from discretionary foods, which was not found to be associated with the proportion of daily plain water in total dietary water consumption among non-Hispanic African Americans, Hispanics, adults aged ≥65 years, individuals at the lowest income level, as well as normal weight or obese adults. No systematic differences in the relationship between daily dietary patterns and the proportion of daily plain water in total dietary water consumption were found between population subgroups by race/ethnicity, education attainment, income level or body weight status. By contrast, compared with women and adults aged ≥65 years, a significantly larger reduction in the daily consumption of total energy, energy from SSBs, total fat, saturated fat, sugar, sodium and cholesterol associated with an increase in the proportion of daily plain water in total dietary water consumption was found in men and younger adults aged 18–64 years, respectively. Daily overall diet quality measured by the HEI-2010 was not found to be associated with the proportion of daily plain water in total dietary water consumption in any of the population subgroups under investigation. The only exceptions were older adults aged ≥65 years and people at the lowest income level, among whom a rather small but statistically significant decrease (−0.04 and −0.02, respectively) in the HEI-2010 score in response to a one percentage point increase in the proportion of daily plain water in total dietary water consumption was identified.

Table 1 Individual characteristics of adult study participants, National Health and Nutrition Examination Survey (NHANES) 2005–2012

Individual characteristics	Mean/proportion (95% confidence interval)
Daily water intake	
Plain (tap or bottled) water (g)	999.00 (965.17, 1032.83)
Total dietary water from beverages/foods (g)	2934.27 (2888.43, 2980.12)
Percentage of plain water in total dietary water	30.41 (29.69, 31.14)
Daily dietary intake	
Total energy (kcal) kcal	2157.31 (2134.76, 2179.86)
Energy from sugar-sweetened beverages (kcal)	124.96 (118.44, 131.48)
Energy from discretionary foods (kcal)	431.52 (420.82, 442.22)
Total fat (g)	79.94 (78.81, 81.07)
Saturated fat (g)	26.27 (25.83, 26.70)
Sugar (g)	116.80 (115.05, 118.56)
Sodium (mg)	3503.14 (3465.75, 3540.53)
Cholesterol (mg)	282.85 (278.71, 286.98)
Healthy Eating Index-2010 (score = 0–100)	48.86 (48.37, 49.36)
Sex (%)	
Male	49.37 (48.75, 49.99)
Female	50.63 (50.01, 51.25)
Race/ethnicity (%)	
White, non-Hispanic	68.40 (64.91, 71.89)
African American, non-Hispanic	11.61 (9.73, 13.49)
Other race/multi-race, non-Hispanic	6.61 (5.60, 7.62)
Hispanic	13.38 (11.10, 15.66)
Age group (%)	
18–64 years	82.81 (81.75, 83.88)
65 years	17.19 (16.12, 18.25)
Education (%)	
High school education and below	40.94 (38.81, 43.07)
College education and above	55.45 (53.37, 57.53)
Income to poverty ratio (IPR) (%)	
IPR < 130%	20.71 (19.26, 22.16)
130% ≤ IPR < 300%	27.08 (25.70, 28.46)
IPR ≥ 300%	45.53 (43.35, 47.72)
Body weight status (%)	
Underweight (BMI < 18.5)	1.97 (1.68, 2.26)
Normal weight (18.5 ≤ BMI < 25)	30.99 (29.75, 32.24)
Overweight (25 ≤ BMI < 30)	32.87 (31.84, 33.89)
Obese (BMI ≥ 30)	32.86 (31.68, 34.04)

Individual-level data (n = 22 231) came from the NHANES 2005–2012 waves. The descriptive statistics account for the NHANES multiyear complex survey design. Proportions may not add to 100% as a result of missing values in some individual characteristics. BMI, body mass index.

Based on the simulation outcomes, an increase in daily plain water consumption by one, two and three US cups at the same time as holding daily total dietary water consumption constant resulted in a reduction in daily total energy intake by 68.64, 137.28 and 205.92 kcal, energy intake from SSBs by 11.44, 22.88 and 34.32 kcal, energy

Table 2 Estimated hanges in daily diet associated with one percentage point increase in the proportion of daily plain water in total dietary water consumption among US adults

Sample	Total energy (kcal)	Energy from SSBs (kcal)	Energy from discretionary foods (kcal)	Total fat (g)	Saturated fat (g)	Sugar (g)	Sodium (mg)	Cholesterol (mg)	HEI-2010 (score)
All (n = 18 311)	−8.58*** (−9.29, −7.87)	−1.43*** (−1.59, −1.27)	−0.88*** (−1.32, −0.44)	−0.21*** (−0.25, −0.17)	−0.07*** (−0.09, −0.06)	−0.74*** (−0.82, −0.67)	−9.80*** (−11.39, −8.20)	−0.88*** (−1.13, −0.64)	−0.01 (−0.02, 0.00)
Male (n = 9031)	−10.66*** (−11.92, −9.40)	−1.78*** (−2.08, −1.48)	−1.10**0 (−1.88, −0.32)	−0.26*** (−0.33, −0.20)	−0.10*** (−0.13, −0.08)	−0.83*** (−0.96, −0.70)	−12.26*** (−14.80, −9.72)	−1.21*** (−1.61, −0.80)	−0.01 (−0.02, 0.01)
Female (n = 9280)	−6.55*** (−7.44, −5.67)	−1.10*** (−1.27, −0.94)	−0.67* (−1.23, −0.12)	−0.15*** (−0.20, −0.10)	−0.05*** (−0.06, −0.03)	−0.65*** (−0.72, −0.59)	−7.41*** (−9.43, −5.39)	−0.57*** (−0.81, −0.33)	−0.01 (−0.03, 0.01)
Non-Hispanic white (n = 8443)	−8.39*** (−9.40, −7.38)	−1.23*** (−1.47, −0.99)	−0.96** (−1.61, −0.31)	−0.20*** (−0.25, −0.15)	−0.08*** (−0.10, −0.06)	−0.74*** (−0.86, −0.62)	−9.03*** (−11.39, −6.67)	−0.89*** (−1.22, −0.56)	−0.01 (−0.03, 0.01)
Non-Hispanic black (n = 4066)	−8.90*** (−10.35, −7.45)	−2.18*** (−2.57, −1.79)	−0.65 (−1.33, 0.02)	−0.19*** (−0.27, −0.11)	−0.07*** (−0.10, −0.04)	−0.93*** (−1.04, −0.83)	−8.77*** (−11.50, −6.03)	−0.88*** (−1.25, −0.50)	−0.02 (−0.04, 0.01)
Hispanic (n = 4575)	−8.90*** (−10.59, −7.21)	−1.67*** (−2.00, −1.34)	−0.32 (−1.07, 0.43)	−0.23*** (−0.31, −0.15)	−0.07*** (−0.10, −0.04)	−0.61*** (−0.73, −0.50)	−10.53*** (−13.43, −7.63)	−0.85*** (−1.24, −0.45)	−0.01 (−0.03, 0.01)
18–64 years (n = 14 004)	−9.31*** (−10.19, −8.43)	−1.59*** (−1.78, −1.41)	−1.13*** (−1.64, −0.62)	−0.23*** (−0.27, −0.18)	−0.08*** (−0.10, −0.06)	−0.80*** (−0.89, −0.72)	−10.48*** (−12.26, −8.70)	−0.96*** (−1.24, −0.68)	−0.00 (−0.02, 0.01)
≥65 years (n = 4307)	−4.31*** (−5.78, −2.84)	−0.47*** (−0.71, −0.22)	0.48 (−0.29, 1.26)	−0.08* (−0.16, −0.00)	−0.04** (−0.06, −0.01)	−0.39*** (−0.50, −0.27)	−5.84*** (−8.86, −2.83)	−0.42* (−0.82, −0.03)	−0.04* (−0.07, −0.01)
Education ≤ high school (n = 8582)	−8.48*** (−9.42, −7.54)	−1.69*** (−1.98, −1.41)	−0.94** (−1.56, −0.32)	−0.19*** (−0.24, −0.14)	−0.07*** (−0.09, −0.05)	−0.72*** (−0.82, −0.63)	−8.87*** (−11.34, −6.39)	−0.72*** (−1.08, −0.36)	−0.00 (−0.02, 0.02)
Education ≥ college (n = 8575)	−8.52*** (−9.62, −7.42)	−1.21*** (−1.44, −0.98)	−0.89** (−1.51, −0.27)	−0.21*** (−0.27, −0.15)	−0.08*** (−0.10, −0.06)	−0.73*** (−0.84, −0.62)	−10.43*** (−12.98, −7.88)	−0.93*** (−1.30, −0.56)	−0.01 (−0.03, 0.01)
IPR < 130% (n = 5436)	−7.44*** (−8.90, −5.98)	−1.66*** (−2.04, −1.29)	−0.74 (−1.58, 0.11)	−0.14*** (−0.21, −0.08)	−0.05*** (−0.08, −0.03)	−0.80*** (−0.93, −0.66)	−7.92*** (−10.79, −5.05)	−0.82*** (−1.17, −0.47)	−0.02* (−0.04, −0.00)
130% ≤ IPR < 300% (n = 5303)	−9.89*** (−11.31, −8.46)	−1.60*** (−1.98, −1.21)	−1.00* (−1.79, −0.21)	−0.27*** (−0.35, −0.18)	−0.09*** (−0.12, −0.06)	−0.82*** (−0.98, −0.67)	−10.95*** (−13.49, −8.41)	−1.07*** (−1.56, −0.58)	0.00 (−0.02, 0.03)
IPR ≥ 300% (n = 6193)	−8.64*** (−9.98, −7.30)	−1.22*** (−1.45, −1.00)	−0.90* (−1.63, −0.16)	−0.21*** (−0.28, −0.15)	−0.08*** (−0.11, −0.05)	−0.69*** (−0.81, −0.58)	−10.10*** (−13.03, −7.18)	−0.83*** (−1.27, −0.39)	−0.00 (−0.03, 0.02)
Normal weight (n = 5247)	−8.09*** (−9.62, −6.57)	−1.36*** (−1.66, −1.06)	−0.52 (−1.41, 0.37)	−0.13** (−0.21, −0.06)	−0.05** (−0.08, −0.02)	−0.80*** (−0.93, −0.68)	−8.46*** (−11.56, −5.36)	−0.74** (−1.16, −0.32)	−0.02 (−0.05, 0.00)
Overweight (n = 5995)	−9.15*** (−10.52, −7.78)	−1.46*** (−1.76, −1.17)	−1.60*** (−2.46, −0.74)	−0.23*** (−0.30, −0.16)	−0.08*** (−0.10, −0.05)	−0.73*** (−0.86, −0.59)	−10.08*** (−12.40, −7.76)	−1.13*** (−1.56, −0.70)	−0.00 (−0.03, 0.02)
Obese (n = 6483)	−8.53*** (−9.79, −7.27)	−1.49*** (−1.75, −1.24)	−0.67 (−1.49, 0.15)	−0.24*** (−0.31, −0.17)	−0.09*** (−0.12, −0.07)	−0.71*** (−0.82, −0.60)	−10.94*** (−13.63, −8.24)	−0.77** (−1.20, −0.34)	−0.00 (−0.02, 0.02)

Individual-level data came from the National Health and Nutrition Examination Survey (NHANES) 2005–2012 waves. First-difference estimators were used to estimate the changes in daily diet associated with one percentage point increase in the proportion of daily plain water in total water consumption among US adults, adjusting for whether the consumption was on a weekday or weekend and accounting for the NHANES multiyear complex survey design. SSB, sugar-sweetened beverage; IPR, income poverty ratio; 95% confidence intervals are given in parentheses.

*0.01 ≤ P < 0.05.

**0.001 ≤ P < 0.01.

***P < 0.001.

intake from discretionary foods by 7.04, 14.08 and 21.12 kcal, total fat intake by 1.68, 3.36 and 5.04 g, saturated fat intake by 0.56, 1.12 and 1.68 g, sugar intake by 5.92, 11.84 and 17.76 g, sodium intake by 78.4, 156.8 and 235.2 mg, and cholesterol intake by 7.04, 14.08 and 21.12 g, respectively.

Discussion

The present study examined plain water consumption in relation to energy/nutrient intake and diet quality among the US adult population using data from a nationally representative survey. On average, US adults consumed approximately 999 g of plain water, including tap and bottled water, on a daily basis, which was substantially higher than that consumed in Britain (432 g) and France (564 g), and was comparable with that consumed in Canada (range 705–1065 g, contingent upon adult age group) [30]. An increase in the proportion of daily plain water in total dietary water consumption was found to be associated with reduced daily intake of total energy, energy from SSBs, energy from discretionary foods (for certain subgroups only), and total fat, saturated fat, sugar, sodium and cholesterol in both the overall adult population and all subgroups under investigation. The reductions were larger among males and young/middle-aged adults than among females and older adults, respectively. In general, the proportion of daily plain water in total dietary water consumption was not found to be associated with daily overall diet quality measured by the HEI-2010.

The finding of the inverse relationship between plain water consumption and energy intake coincides with the results from previous experimental and epidemiological studies. Pre-meal water consumption was documented to reduce meal energy intake in clinical interventions involving overweight and obese older adults [12,14]. Replacing sweetened caloric beverages with drinking water was found to decrease total energy intake and the effect sustained over time [31]. In a large cross-sectional study on Mexican adults with low socio-economic status, higher plain water consumption was found to be associated with lower intake of caloric beverages [32]. Kant *et al.* [17] reported total dietary water intake to be inversely related to energy from fat and energy density.

Compared with their female and older counterparts, the larger reductions in energy intake associated with plain water consumption among male and young/middle-aged adults were likely a result of their higher daily energy consumption level. By contrast, the impacts of plain water intake on diet were similar across race/ethnicity, education attainment, income level and body weight status. The finding indicates that it might be sufficient to design and deliver universal nutrition interventions and education campaigns that promote plain water consumption in place of caloric beverages in diverse population subgroups without profound concerns about message and strategy customisation.

By contrast to our hypothesis, plain water intake was not found to be associated with daily overall diet quality measured by the HEI-2010. This result could partially be a result of the rather small daily variations in the proportion of plain water in total dietary water consumption. Between the two nonconsecutive 24-h dietary recalls that were 3–10 days apart, the proportion of plain water in total dietary water consumption on average changed by <0.74% among NHANES participants. Such a marginal change in plain water consumption is unlikely to result in significant shifts in daily overall diet quality. On the other hand, a tiny but statistically significant decrease in the HEI-2010 score in response to an increase in the proportion of daily plain water in total dietary water consumption was found among older adults and individuals at the lowest income level. This finding raises an important caveat in the promotion of plain water consumption. The emphasis of the message should be to encourage people to consume plain water in place of sugar-sweetened beverages rather than low-energy-dense nutrient-rich beverages, such as reduced-fat milk.

The results of existing research regarding the beneficial health effects of plain water consumption are not unanimous. Akers *et al.* (2012) reported daily self-monitoring of water consumption to be a feasible and effective long-term weight loss maintenance approach [33]. Stookey *et al.* (2008) reported drinking water to lead to weight loss in overweight dieting women independent of diet and activity [34]. By contrast, Hernández-Cordero *et al.* (2014) found that replacing water for SSBs reduced circulating triglycerides and the risk of the metabolic syndrome in obese but not in overweight Mexican women [7]. Sichieri *et al.* (2013) did not find a protective effect of water consumption on BMI [35]. Peters *et al.* (2014) found water not to be superior to non-nutritive beverages for weight loss in a behavioural weight-loss programme [36].

A few limitations of the present study should be noted. NHANES is a probability sample of the US non-institutionalised population, and patients in penal/mental facilities, institutionalised older adults and/or military personnel on active duty are not represented. Dietary intakes in NHANES were self-reported and subject to measurement error and social desirability bias [37]. The first-difference estimator eliminated confounding bias from unobservable factors that remained constant within-participant between the two dietary interviews but could not control for more transient factors such as daily variations in physical activity, appetite or emotions. The dietary recall method in estimating plain water consumption is likely to result in an underestimation because water intake occasions are often forgotten. Despite its panel study design, the present study is observational in nature, and the findings warrant confirmation through controlled interventions. Moreover, more research needs to be conducted aiming to investigate the potential population heterogeneity in plain water consumption and its diet/health implications, especially for the underserved and vulnerable populations, such as low-income or less educated people, older adults and overweight/obese individuals.

In conclusion, the present study examined plain water consumption in relation to energy/nutrient intake and diet quality among US adults using nationally representative data. An increase in the proportion of daily plain water in total dietary water consumption was found to be associated with a decreased daily intake of total energy, energy from SSBs and discretionary foods, and total fat, saturated fat, sugar, sodium and cholesterol. Promoting plain water intake could be a useful public health strategy for reducing energy and targeted nutrient consumption in US adults, which warrants confirmation in future controlled interventions.

Transparency declaration

The lead author (RA) affirms that this manuscript is an honest, accurate and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned (and registered with) have been explained. The reporting of this work is compliant with STROBE guidelines.

Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.

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RA initiated the study, conducted the analysis and wrote the manuscript. JM contributed to the interpretation of the results and drafting of the manuscript. All authors critically reviewed the manuscript and approved the final version submitted for publication.

References

1. Popkin BM, D'Anci KE & Rosenberg IH (2010) Water, hydration and health. *Nutr Rev* **68**, 439–458.
2. Campbell SM (2007) Hydration needs throughout the lifespan. *J Am Coll Nutr* **26**, 585S–587S.
3. Dennis EA, Flack KD & Davy BM (2009) Beverage consumption and adult weight management: a review. *Eat Behav* **10**, 237–246.
4. Muckelbauer R, Sarganas G, Grüneis A *et al.* (2013) Association between water consumption and body weight outcomes: a systematic review. *Am J Clin Nutr* **98**, 282–299.
5. Stookey JD (2010) Drinking water and weight management. *Nutr Today* **45**, S7–S12.
6. Tate DF, Turner-McGrievy G, Lyons E *et al.* (2012) Replacing caloric beverages with water or diet beverages for weight loss in adults: main results of the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. *Am J Clin Nutr* **95**, 555–563.
7. Hernández-Cordero S, Barquera S, Rodríguez-Ramírez S *et al.* (2014) Substituting water for sugar-sweetened beverages reduces circulating triglycerides and the prevalence of metabolic syndrome in obese but not in overweight Mexican women in a randomized controlled trial. *J Nutr* **144**, 1742–1752.
8. Dennis EA, Dengo AL, Comber DL *et al.* (2010) Water consumption increases weight loss during a hypocaloric diet intervention in middle-aged and older adults. *Obesity (Silver Spring)* **18**, 300–307.
9. US Department of Agriculture & US Department of Health and Human Services (2010) Dietary Guidelines for Americans 2010 , 7th edn. Available at: http://www.health.gov/dietaryguidelines/dga2010/dietaryguidelines2010.pdf (accessed November 2015).
10. Ritchie L, Gortmaker SL, Popkin B *et al.* (2015) Best of Science Letter on Drinking Water. Available at: http://npi.ucanr.edu/files/207504.pdf (accessed November 2015).
11. Daniels MC & Popkin BM (2010) The impact of water intake on energy intake and weight status: a systematic review. *Nutr Rev* **68**, 505–521.
12. Davy BM, Dennis EA, Dengo AL *et al.* (2008) Water consumption reduces energy intake at a breakfast meal in obese older adults. *J Am Diet Assoc* **108**, 1236–1239.
13. van de Gaar VM, Jansen W, van Grieken A *et al.* (2014) Effects of an intervention aimed at reducing the intake of sugar-sweetened beverages in primary school children: a controlled trial. *Int J Behav Nutr Phys Act* **11**, 98.
14. Van Walleghen EL, Orr JS, Gentile CL *et al.* (2007) Pre-meal water consumption reduces meal energy intake in older but not younger subjects. *Obesity (Silver Spring)* **15**, 93–99.
15. Popkin, BM, Barclay, DV, Nielsen SJ (1999) Water food consumption patterns of US adults from to 2001. *Obes Res* **13**, 2146–2152.
16. Wang YC, Ludwig DS, Sonneville K *et al.* (2009) Impact of change in sweetened caloric beverage consumption on energy intake among children and adolescents. *Arch Pediatr Adolesc Med* **163**, 336–343.

17. Kant AK, Graubard BI & Atchison EA (2009) 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. *Am J Clin Nutr* **90**, 655–663.
18. Drewnowski A, Rehm CD & Constant F (2013) Water and beverage consumption among children age 4–13y in the United States: analyses of 2005–2010 NHANES data. *Nutr J* **12**, 85.
19. Drewnowski A, Rehm CD & Constant F (2013) Water and beverage consumption among adults in the United States: cross-sectional study using data from NHANES 2005–2010. *BMC Public Health* **13**, 1068.
20. Faith MS, Kral TVE (2006) Social environmental and genetic influences on obesity and obesity-promoting behaviors: fostering research integration. In: *Genes, Behavior, and the Social Environment: Moving Beyond the Nature/Nurture Debate*. pp.236–280 [Hernandez LM & Blazer DG, editors]. Washington (DC): National Academies Press. Available at: http://www.ncbi.nlm.nih.gov/books/NBK19935/ (accessed November 2015).
21. National Cancer Institute (2014) Sources of Beverage Intakes Among the US Population, 2005–06. Available at: http://riskfactor.cancer.gov/diet/foodsources/beverages/ (accessed November 2015).
22. Ogden CL, Kit BK, Carroll MD *et al.* , (2011) Consumption of sugar drinks in the United States, 2005–2008. *NCHS Data Brief* **71**, 1–8.
23. National Health and Medical Research Council (2013) *Australian Dietary Guidelines* Canberra, Australia: NHMRC. Available at: https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/n55_australian_dietary_guidelines_130530.pdf (accessed November 2015).
24. Bleich SN, Wolfson JA, Vine S *et al.* (2014) Diet-beverage consumption and caloric intake among US adults, overall and by body weight. *Am J Public Health* **104**, e72–e78.
25. An R (2016) Beverage consumption in relation to discretionary food intake and diet quality among US adults, 2003–2012. *J Acad Nutr Diet* **116**, 28–37.
26. Guenther PM, Casavale KO, Reedy J *et al.* (2013) Update of the Healthy Eating Index: HEI-2010. *J Acad Nutr Diet* **113**, 569–580.
27. Bowman, SAFriday, JEMoshfegh, AJ (2008) MyPyramid Equivalents Database, 2.0 for USDA Survey Foods, 2003–2004. Available at: http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/mped/mped2_doc.pdf (accessed November 2015).
28. National Cancer Institute (2015) HEI Tools for Researchers. Available at: http://appliedresearch.cancer.gov/hei/tools.html (accessed November 2015).
29. World Health Organization (2006) The International Classification of Adult Underweight, Overweight and Obesity According to BMI. Available at: http://apps.who.int/bmi/index.jsp?introPage=intro_3.html (accessed November 2015).
30. Gibson S, Gunn P & Maughan RJ (2012) Hydration, water intake and beverage consumption habits among adults. *Nutrition Bulletin* **37**, 182–192.
31. Stookey JD, Constant F, Gardner CD *et al.* (2007) Replacing sweetened caloric beverages with drinking water is associated with lower energy intake. *Obesity (Silver Spring)* **15**, 3013–3022.
32. Illescas-Zarate D, Espinosa-Montero J, Flores M *et al.* (2015) Plain water consumption is associated with lower intake of caloric beverage: cross-sectional study in Mexican adults with low socioeconomic status. *BMC Public Health* **15**, 405.
33. Akers JD, Cornett RA, Savla JS *et al.* (2012) Daily self-monitoring of body weight, step count, fruit/vegetable intake, and water consumption: a feasible and effective long-term weight loss maintenance approach. *J Acad Nutr Diet* **112**, 685–692.
34. Stookey JD, Constant F, Popkin BM *et al.* (2008) Drinking water is associated with weight loss in overweight dieting women independent of diet and activity. *Obesity* **16**, 2481–2488.
35. Sichieri R, Yokoo EM, Pereira RA *et al.* (2013) Water and sugar-sweetened beverage consumption and changes in BMI among Brazilian fourth graders after 1-year follow-up. *Public Health Nutr* **16**, 73–77.
36. Peters JC, Wyatt HR, Foster GD *et al.* (2014) The effects of water and non-nutritive sweetened beverages on weight loss during a 12-week weight loss treatment program. *Obesity* **22**, 1415–1421.
37. Hebert JR, Hurley TG, Peterson KE *et al.* (2008) Social desirability trait influences on self-reported dietary measures among diverse participants in a multicenter multiple risk factor trial. *J Nutr* **138**, 226S–234S.

