Soda and Other Beverages and the Risk of Kidney Stones

Pietro Manuel Ferraro,*† Eric N. Taylor,† Giovanni Gambaro,* and Gary C. Curhan†‡

Summary

Background and objectives Not all fluids may be equally beneficial for reducing the risk of kidney stones. In particular, it is not clear whether sugar and artificially sweetened soda increase the risk.

Design, setting, participants, & measurements We prospectively analyzed the association between intake of several types of beverages and incidence of kidney stones in three large ongoing cohort studies. Information on consumption of beverages and development of kidney stones was collected by validated questionnaires.

Results The analysis involved 194,095 participants; over a median follow-up of more than 8 years, 4462 incident cases occurred. There was a 23% higher risk of developing kidney stones in the highest category of consumption of sugar-sweetened cola compared with the lowest category (*P* for trend=0.02) and a 33% higher risk of developing kidney stones for sugar-sweetened noncola (*P* for trend=0.003); there was a marginally significant higher risk of developing kidney stones for artificially sweetened noncola (*P* for trend=0.05). Also, there was an 18% higher risk for punch (*P* for trend=0.04) and lower risks of 26% for caffeinated coffee (*P* for trend<0.001), 16% for decaffeinated coffee (*P* for trend=0.01), 11% for tea (*P* for trend=0.02), 31%–33% for wine (*P* for trend<0.005), 41% for beer (*P* for trend<0.001), and 12% for orange juice (*P* for trend=0.004).

Conclusions Consumption of sugar-sweetened soda and punch is associated with a higher risk of stone formation, whereas consumption of coffee, tea, beer, wine, and orange juice is associated with a lower risk.

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*Division of Nephrology—Renal Program, Department of Internal Medicine and Medical Specialties, Catholic University of the Sacred Heart, Rome, Italy; †Channing Division of Network Medicine, Department of Medicine, Brigham and Women's Hospital, Boston, Massachusetts; and ‡Renal Division, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts

Correspondence: Dr. Pietro Manuel Ferraro, Division of Nephrology–Renal Program, Department of Internal Medicine and Medical Specialties, Catholic University of the Sacred Heart, 00168 Rome, Italy. Email: manuel.ferraro@channing.harvard.edu

Introduction

Nephrolithiasis is a common and recurrent condition. Based on a recent analysis of the National Health And Nutrition Examination Survey 2007–2010 data, the prevalence of a history of nephrolithiasis in the United States was 10.6% for men and 7.1% for women (1). Recurrences are common, because approximately 25% of untreated patients experience a new episode within 5 years (2). In addition to the pain and suffering, the medical costs associated with kidney stones exceed $2 billion annually, and there are additional costs because of missed work (3,4).

Dietary interventions have proven effective in reducing the risk of developing kidney stones. In particular, increasing fluid intake is a well accepted method for reducing the recurrence of stones (2). Nevertheless, not all types of fluids may be equally beneficial; some beverages, like sodas (5–7), have an increased risk of stones reported, and others, like coffee and tea, have been reported to be associated with a reduced risk of stone formation (8,9).

Soda is popular in the general population. In a representative sample of the US population, the proportion of individuals who reported drinking sugar-sweetened beverages daily increased from 58% in the 1988–1994 period to 63% in the 1999–2004 period (10). Several small studies have investigated the effect of soda on urinary composition in healthy volunteers with inconsistent results (11–14). Relatively small cross-sectional (5) and case-control (6) studies as well as a randomized controlled study (7) suggested an association between soda and history (5,6) or recurrence (7) of kidney stones without further exploring the specific beverage (*e.g.*, cola or sugar-sweetened sodas versus artificially sweetened versions). This issue may be important, because sugar-sweetened beverages contain fructose, which has been found to be associated with kidney stones (15) as well as known risk factors for kidney stones, such as gout (16,17) and obesity (18). Also, it has been postulated that cola-containing beverages may have differential effects on urine composition and hence, lithogenic risk compared with noncolas, with the former containing the potentially lithogenic orthophosphoric acid and the latter containing citric acid, which may increase urinary citrate excretion and reduce the risk of stones (19).

The main aim of our study was to investigate the association between different types of sodas (sugar-sweetened or artificially sweetened cola and noncola) and the incidence of kidney stones in individuals without a history of nephrolithiasis. We also assessed the association between other types of beverages and risk of kidney stones. This study updates our previous reports in two of the cohorts (8,9) and provides information from another independent cohort.

Materials and Methods

Study Population

This study analyzed data from three ongoing cohorts. The Health Professionals Follow-Up Study (HPFS) enrolled 51,529 men health professionals between the ages of 40 and 75 years in 1986. The Nurses' Health Study I (NHS I) enrolled 121,700 women nurses between the ages of 30 and 55 years in 1976, and the Nurses' Health Study II (NHS II) enrolled 116,430 women nurses between the ages of 25 and 42 years in 1989.

Participants in all the three cohorts have been asked to complete biennial questionnaires with information on medical history, lifestyle, and medications; most information was updated every 2 years, whereas diet was updated every four years.

Individuals with history of kidney stones or cancer (except for nonmelanoma skin cancer) at baseline were excluded from the analysis. Individuals who developed cancer during follow-up were censored.

Assessment of Beverage Use

In 1986 (HPFS and NHS I) and 1991 (NHS II), participants returned a food-frequency questionnaire (FFQ) that asked about the use of more than 130 foods, beverages, and supplements in nine categories in the previous year, and dietary information was updated every 4 years. The validity and reliability of the self-reported FFQs were shown in subgroups of the main cohorts (20,21). The correlation coefficients ranged from 0.55 to 0.84 for sodas.

In the analyses, individuals were divided into categories according to consumption of less than 1 serving per week, 1 serving per week, 2–4 servings per week, 5–6 servings per week, and 1 or more servings per day of each individual beverage. The serving size was defined differently for different beverages (*e.g.*, a glass [8 oz] for coffee, tea, milk, and water, a small glass for juices, a glass, bottle, or can for carbonated beverages and beer, a 5 oz glass for wine, and a drink or shot for liquor).

We used the term noncola for carbonated beverages without cola (*e.g.*, clear soda).

Assessment of Incident Kidney Stones

The primary end point was an incident kidney stone accompanied by pain or hematuria. Individuals who reported a new kidney stone on a questionnaire were sent a supplementary questionnaire to determine the date of occurrence and symptoms. Medical records from 582 men in HPFS, 194 women in NHS I, and 858 women in NHS II confirmed the diagnosis in 95%, 96%, and 98% of the reports, respectively; among those individuals whose medical records included a stone composition report, 86% of participants in the HPFS, 77% of participants in the NHS I, and 79% of participants in the NHS II cohort had a stone containing ≥50% of calcium (22).

Other Covariates

Information on participants' age, height, weight, race (white/nonwhite), region of residence (West/Midwest/South/Northeast), profession, use of furosemide or thiazides, and diagnosis of diabetes, high BP, and gout was collected. Daily intakes of calcium, potassium, phytate, animal protein, vitamin C, alcohol, and total energy were computed from the FFQ. Two validation studies have shown the validity of the FFQ (20,21).

Statistical Analyses

Age-adjusted incidence rates of kidney stones were computed across categories of consumption of each type of beverage. The hazard ratio and 95% confidence interval (95% CI) for developing kidney stones in each category of exposure compared with the lowest category were computed in each cohort using Cox proportional hazards models adjusted for age, region of residence, body mass index, use of thiazides, use of furosemide, history of diabetes, high BP, and gout, and daily intake of calcium (including supplements), potassium, phytate, animal protein, vitamin C, alcohol, and total energy. The model was further mutually adjusted for all the other types of beverages. Exposure and covariates were updated every 4 years using simple exposure updating (*e.g.*, during each 4-year period, a participant would contribute person-time to the category of intake reported at the start of that time period). The coefficients for whole and skim milk and juices were estimated from a separate model that did not include calcium and potassium intake, respectively, to avoid adjusting for the potentially active factor in dairy products and the factor associated with alkali in foods. For the HPFS cohort, the model was also adjusted for profession.

Time at risk was 1986–2006 for HPFS and NHS I and 1991–2007 for NHS II. However, from 2002 (for NHS I) and 2003 (for NHS II), the questionnaires changed with regard to soda items; therefore, we calculated estimates for sodas until that time period and used different variables (sugar-sweetened and artificially sweetened soda) for the remaining time at risk.

To assess the trends across categories of consumption of soda and incidence of kidney stones, we also evaluated intake continuously using the median value of servings per week in each category. Stratified analyses were performed for age (<50 versus ≥50 years), body mass index (<18.5, 18.5–24.9, and ≥25.0 kg/m^2), and cohort. The results of the three cohorts were pooled using random effects meta-analysis. A P value<0.05 was considered statistically significant. Analyses were performed using SAS version 9.1.

Results

The baseline characteristics of 194,095 participants according to the study cohort are detailed in Table 1. The median follow-up times were 8 years for the HPFS and NHS II cohorts and 13 years for the NHS I cohort. The combined person-time contributed to the analysis from the three cohorts was 2,643,708 person-years.

We report the combined results for the three cohorts after testing for heterogeneity (the only coefficient with heterogeneity that was statistically significant across cohorts was the coefficient for decaffeinated coffee).

Soda Beverages

Participants consuming one or more sugar-sweetened cola servings per day had a 23% (95% CI=−2% to 55%) higher risk of developing kidney stones compared with those participants consuming less than one serving per

Table 1. Baseline characteristics of the study population according to cohort

	HPFS (n=42,991)	NHS I (n=62,252)	NHS II (n=88,852)
Age (yr)	54 (10)	51 (7)	37 (5)
Nonwhites (%)	4.8	5.5	5.9
Diabetes (%)	2.8	2.9	1.0
High BP (%)	21.4	20.8	6.4
Gout (%)	5.1	1.8	0.3
Body mass index (kg/m^2)[a]	25 (24, 27)	24 (22, 27)	23 (21, 27)
Use of thiazides (%)	9.2	12.8	1.8
Daily intakes			
Calcium (mg)[a]	766 (559, 1125)	826 (591, 1199)	908 (644, 1297)
Potassium (mg)[a]	3263 (2608, 4019)	3001 (2417, 3667)	2808 (2236, 3471)
Animal proteins (g)[a]	64 (49, 80)	54 (42, 68)	61 (47, 77)
Phytate (mg)[a]	844 (615, 1139)	661 (495, 877)	724 (547, 946)
Vitamin C (mg)[a]	227 (137, 517)	194 (120, 384)	157 (99, 260)
Alcohol (g)[a]	5.8 (0.9, 14.9)	2.0 (0.0, 9.1)	0.9 (0.0, 3.5)
Energy (cal)	1989 (618)	1746 (527)	1791 (547)
Sugar-sweetened cola (servings/mo)[a]	2 (2, 5)	2 (2, 3)	2 (2, 5)
Artificially sweetened cola (servings/mo)[a]	2 (2, 13)	3 (2, 14)	13 (2, 32)
Sugar-sweetened noncola (servings/mo)[a]	1 (1, 2)	1 (1, 2)	1 (1, 2)
Artificially sweetened noncola (servings/mo)[a]	1 (1, 2)	1 (1, 4)	1 (1, 2)
Coffee (servings/mo)[a]	26 (1, 75)	30 (1, 75)	12 (1, 75)
Decaffeinated coffee (servings/mo)[a]	2 (1, 26)	2 (1, 30)	1 (1, 4)
Tea (servings/mo)[a]	2 (1, 12)	2 (1, 30)	4 (1, 30)
Red wine (servings/mo)[a]	1 (1, 2)	1 (1, 2)	1 (1, 1)
White wine (servings/mo)[a]	2 (1, 4)	1 (1, 4)	1 (1, 2)
Beer (servings/mo)[a]	2 (1, 12)	1 (1, 1)	1 (1, 1)
Liquor (servings/mo)[a]	2 (1, 12)	1 (1, 2)	1 (1, 1)
Apple juice (servings/mo)[a]	1 (1, 2)	1 (1, 2)	1 (1, 2)
Grapefruit juice (servings/mo)[a]	1 (1, 2)	1 (1, 2)	1 (1, 1)
Orange juice (servings/mo)[a]	12 (2, 26)	12 (2, 30)	4 (2, 12)
Tomato juice (servings/mo)[a]	1 (1, 2)	1 (1, 2)	1 (1, 2)
Other juice (servings/mo)[a]	1 (1, 2)	1 (1, 4)	2 (1, 4)
Punch (servings/mo)[a]	1 (1, 2)	1 (1, 2)	2 (1, 4)
Whole milk (servings/mo)[a]	1 (1, 1)	1 (1, 2)	1 (1, 1)
Skim milk (servings/mo)[a]	12 (1, 30)	12 (1, 30)	26 (4, 30)
Water (servings/mo)[a]	75 (30, 135)	75 (30, 135)	75 (30, 135)

Continuous variables reported as mean (SD). HPFS, Health Professionals Follow-Up Study; NHS I, Nurses' Health Study I; NHS II, Nurses' Health Study II.
[a]Median (first and third quartiles).

week (P value for trend=0.02). Participants consuming one or more sugar-sweetened noncola servings per day had a 33% (95% CI=1% to 74%) higher risk compared with those participants consuming less than one serving per week (P value for trend=0.003). Consumption of artificially sweetened sodas (cola and noncola) was marginally associated with kidney stones (Table 2): artificially sweetened cola was associated with a trend to reduced risk, whereas artificially sweetened noncola was associated with a trend to higher risk. After combining sugar-sweetened cola and noncola, the trend was statistically significant (P value for trend$<$0.001), whereas it was not significant for artificially sweetened cola and noncola combined (P value for trend=0.10).

Other Beverages

A significant trend was found for a higher risk of developing kidney stones across categories of consumption of punch; participants consuming one or more servings per day had an 18% (95% CI=1% to 37%) higher risk of developing kidney stones compared with those participants consuming less than one serving per week (P for trend=0.04).

Several beverages showed significant trends for decreased risk of developing kidney stones with increasing consumption. Participants consuming one or more servings of coffee per day had a 26% (95% CI=20% to 31%) lower risk compared with those participants consuming less than one serving per week. Significant trends were also found for decaffeinated coffee (16% risk reduction for the highest category of consumption compared with the lowest; 95% CI=9% to 23%), tea (11% risk reduction for the highest category; 95% CI=3% to 18%), red wine (31% risk reduction; 95% CI=5% to 49%), white wine (33% risk reduction; 95% CI=15% to 45%), beer (41% risk reduction; 95% CI=24% to 54%), and orange juice (12% risk reduction; 95% CI=2% to 21%).

There were no significant interactions between consumption of beverages and the risk of developing kidney stones with age, body mass index, diabetes, and high BP.

Table 2. Relative risk of kidney stones according to categories of consumption of different beverages

	<1/wk	1/wk	2–4/wk	5–6/wk	≥1/d	*P* Value Trend
Sugar-sweetened cola						
Cases (IR)	2962 (149)	555 (193)	443 (236)	117 (262)	385 (287)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.20 (1.00 to 1.44)	1.41 (1.27 to 1.57)	1.52 (1.18 to 1.95)	1.77 (1.40 to 2.22)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	1.07 (0.89 to 1.27)	1.19 (1.06 to 1.34)	1.28 (1.09 to 1.50)	1.23 (0.98 to 1.55)	0.02
Artificially sweetened cola						
Cases (IR)	2381 (174)	454 (166)	564 (170)	181 (174)	882 (158)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.93 (0.75 to 1.14)	0.98 (0.82 to 1.17)	0.94 (0.80 to 1.12)	0.87 (0.76 to 1.00)	0.05
Multivariate HR (95% CI)	1.00 (reference)	1.01 (0.85 to 1.21)	1.05 (0.95 to 1.17)	1.03 (0.87 to 1.21)	0.91 (0.78 to 1.06)	0.08
Sugar-sweetened noncola						
Cases (IR)	3697 (159)	423 (228)	209 (233)	41 (267)	92 (306)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.38 (1.15 to 1.65)	1.37 (1.18 to 1.59)	1.66 (1.21 to 2.28)	1.89 (1.29 to 2.78)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	1.17 (1.00 to 1.38)	1.07 (0.89 to 1.29)	1.22 (0.88 to 1.68)	1.33 (1.01 to 1.74)	0.003
Artificially sweetened noncola						
Cases (IR)	3383 (169)	360 (155)	361 (179)	96 (165)	262 (174)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.95 (0.85 to 1.06)	1.10 (0.89 to 1.35)	1.02 (0.66 to 1.57)	1.13 (0.90 to 1.41)	0.15
Multivariate HR (95% CI)	1.00 (reference)	0.98 (0.85 to 1.13)	1.13 (0.98 to 1.30)	1.04 (0.67 to 1.61)	1.17 (0.98 to 1.41)	0.05
Coffee						
Cases (IR)	2044 (205)	160 (201)	269 (198)	146 (185)	1843 (137)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.94 (0.80 to 1.10)	0.92 (0.81 to 1.04)	0.87 (0.72 to 1.05)	0.68 (0.61 to 0.77)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	0.97 (0.82 to 1.14)	0.94 (0.80 to 1.11)	0.84 (0.64 to 1.11)	0.74 (0.69 to 0.80)	<0.001
Decaffeinated coffee						
Cases (IR)	3098 (180)	233 (178)	285 (169)	97 (143)	749 (136)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.96 (0.84 to 1.10)	0.91 (0.70 to 1.18)	0.80 (0.64 to 1.01)	0.78 (0.68 to 0.90)	0.01
Multivariate HR (95% CI)	1.00 (reference)	1.03 (0.89 to 1.18)	0.92 (0.74 to 1.15)	0.77 (0.63 to 0.95)	0.84 (0.77 to 0.91)	0.01[a]
Tea						
Cases (IR)	2467 (170)	438 (184)	460 (170)	209 (206)	888 (155)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.09 (0.96 to 1.24)	1.01 (0.90 to 1.14)	1.20 (1.04 to 1.38)	0.94 (0.87 to 1.01)	0.33
Multivariate HR (95% CI)	1.00 (reference)	1.10 (0.96 to 1.26)	1.01 (0.90 to 1.13)	1.14 (0.99 to 1.32)	0.89 (0.82 to 0.97)	0.02
Red wine						
Cases (IR)	3944 (174)	260 (160)	179 (132)	36 (125)	43 (96)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.82 (0.65 to 1.04)	0.70 (0.60 to 0.81)	0.55 (0.26 to 1.18)	0.53 (0.39 to 0.72)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	0.97 (0.84 to 1.12)	0.88 (0.72 to 1.06)	0.74 (0.37 to 1.50)	0.69 (0.51 to 0.95)	0.004
White wine						
Cases (IR)	3657 (178)	391 (161)	291 (140)	54 (110)	69 (84)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.85 (0.73 to 0.98)	0.75 (0.63 to 0.89)	0.62 (0.47 to 0.81)	0.52 (0.39 to 0.69)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	0.99 (0.88 to 1.12)	0.93 (0.76 to 1.15)	0.77 (0.58 to 1.01)	0.67 (0.55 to 0.85)	0.002
Beer						
Cases (IR)	3880 (168)	260 (188)	199 (183)	56 (207)	67 (138)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.87 (0.68 to 1.11)	0.66 (0.45 to 0.97)	0.82 (0.63 to 1.08)	0.55 (0.43 to 0.70)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	0.98 (0.81 to 1.19)	0.76 (0.56 to 1.04)	0.91 (0.68 to 1.22)	0.59 (0.46 to 0.76)	<0.001
Liquor						
Cases (IR)	3742 (170)	216 (153)	242 (178)	76 (171)	186 (159)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.80 (0.65 to 0.99)	0.92 (0.78 to 1.08)	0.85 (0.67 to 1.07)	0.85 (0.73 to 0.99)	0.15
Multivariate HR (95% CI)	1.00 (reference)	0.90 (0.77 to 1.06)	1.04 (0.86 to 1.26)	0.90 (0.71 to 1.14)	0.88 (0.75 to 1.04)	0.21

Table 2. (Continued)

	<1/wk	1/wk	2–4/wk	5–6/wk	≥1/d	*P* Value Trend
Apple juice						
Cases (IR)	3639 (164)	431 (187)	282 (214)	54 (228)	56 (191)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.04 (0.89 to 1.22)	1.18 (0.91 to 1.54)	1.20 (0.87 to 1.66)	0.97 (0.60 to 1.56)	0.31
Multivariate HR (95% CI)[b]	1.00 (reference)	0.99 (0.86 to 1.15)	1.11 (0.89 to 1.39)	1.11 (0.76 to 1.61)	0.93 (0.61 to 1.41)	0.58
Grapefruit juice						
Cases (IR)	3899 (168)	258 (175)	181 (170)	43 (164)	81 (186)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.06 (0.89 to 1.25)	1.01 (0.87 to 1.18)	0.99 (0.73 to 1.35)	1.10 (0.85 to 1.44)	0.26
Multivariate HR (95% CI)[b]	1.00 (reference)	1.06 (0.90 to 1.24)	1.02 (0.87 to 1.19)	0.99 (0.73 to 1.35)	1.15 (0.86 to 1.55)	0.22
Orange juice						
Cases (IR)	2094 (167)	605 (185)	717 (175)	271 (173)	775 (158)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.02 (0.82 to 1.27)	0.96 (0.88 to 1.04)	0.95 (0.83 to 1.08)	0.90 (0.77 to 1.04)	0.02
Multivariate HR (95% CI)[b]	1.00 (reference)	0.97 (0.79 to 1.21)	0.91 (0.83 to 1.00)	0.90 (0.79 to 1.02)	0.88 (0.79 to 0.98)	0.004
Tomato juice						
Cases (IR)	3917 (168)	342 (180)	147 (170)	22 (147)	34 (164)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.05 (0.86 to 1.29)	1.03 (0.81 to 1.31)	0.90 (0.59 to 1.37)	1.00 (0.60 to 1.65)	0.81
Multivariate HR (95% CI)[b]	1.00 (reference)	1.04 (0.82 to 1.32)	1.02 (0.77 to 1.35)	0.90 (0.59 to 1.38)	1.01 (0.58 to 1.77)	0.92
Other juice						
Cases (IR)	3140 (161)	542 (195)	465 (199)	112 (179)	203 (181)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.18 (1.07 to 1.29)	1.22 (1.11 to 1.35)	1.11 (0.92 to 1.34)	1.12 (0.97 to 1.29)	0.03
Multivariate HR (95% CI)[b]	1.00 (reference)	1.14 (1.01 to 1.29)	1.18 (1.06 to 1.31)	1.03 (0.85 to 1.25)	1.05 (0.90 to 1.21)	0.14
Punch						
Cases (IR)	3201 (158)	490 (194)	408 (205)	125 (228)	238 (226)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.20 (1.09 to 1.32)	1.33 (1.11 to 1.58)	1.47 (1.23 to 1.76)	1.44 (1.19 to 1.74)	<0.001
Multivariate HR (95% CI)	1.00 (reference)	1.10 (0.99 to 1.21)	1.15 (1.00 to 1.32)	1.21 (1.01 to 1.46)	1.18 (1.01 to 1.37)	0.04
Whole milk						
Cases (IR)	4042 (168)	128 (196)	136 (180)	30 (147)	126 (183)	
Age-adjusted HR (95% CI)	1.00 (reference)	1.17 (0.96 to 1.43)	1.09 (0.83 to 1.42)	0.90 (0.63 to 1.29)	1.10 (0.92 to 1.32)	0.36
Multivariate HR (95% CI)[c]	1.00 (reference)	1.08 (0.89 to 1.31)	0.95 (0.74 to 1.22)	0.79 (0.55 to 1.13)	0.99 (0.82 to 1.19)	0.40
Skim milk						
Cases (IR)	1904 (179)	242 (179)	645 (179)	297 (166)	1374 (152)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.92 (0.75 to 1.13)	0.92 (0.84 to 1.01)	0.86 (0.76 to 0.98)	0.80 (0.75 to 0.86)	<0.001
Multivariate HR (95% CI)[c]	1.00 (reference)	0.96 (0.79 to 1.16)	0.98 (0.89 to 1.08)	0.94 (0.83 to 1.07)	0.91 (0.82 to 1.01)	0.11
Water						
Cases (IR)	447 (204)	124 (186)	261 (196)	195 (193)	3435 (162)	
Age-adjusted HR (95% CI)	1.00 (reference)	0.89 (0.73 to 1.09)	0.95 (0.81 to 1.10)	0.94 (0.76 to 1.15)	0.83 (0.73 to 0.95)	0.002
Multivariate HR (95% CI)	1.00 (reference)	0.88 (0.72 to 1.08)	0.95 (0.81 to 1.11)	0.94 (0.79 to 1.12)	0.90 (0.81 to 1.00)	0.17

Model adjusted for age, race, region of residence, body mass index, use of furosemide, use of thiazides, high BP, diabetes, gout, intake of calcium, potassium, phytate, animal protein, and vitamin C, total calories, and profession (Health Professionals Follow-Up Study); it was mutually adjusted for all the beverages. IR, incidence rate (cases/100,000 person-years); HR, hazard ratio; 95% CI, 95% confidence interval.
[a]Significant heterogeneity between study-specific coefficients.
[b]No adjustment for potassium.
[c]No adjustment for calcium.

We repeated the analysis including body weight and body weight change from age 18 or 21 years, but the results did not change.

Cohort-specific results are listed in Supplemental Table 1.

Discussion

It is well known that higher fluid intake reduces the risk of incident (8,9) and recurrent (2) kidney stones. Our study found that the relation between fluid intake and kidney stones depends on the type of beverage consumed.

Higher consumption of sugar-sweetened soda was associated with a higher incidence of kidney stones, which may be because of the fructose content. Fructose has been shown to increase the urinary excretion of calcium (23), oxalate (23), and uric acid (24), thus increasing the risk of stones (15).

Artificially sweetened sodas were marginally associated with kidney stones, with an inverse relation for colas and a direct relation for noncolas. A previously published analysis of two of three study cohorts reported no significant association between soda beverages and development of kidney stones (8,9). The apparent inconsistency may be explained by differences in the number of cases and person-time available.

We confirmed the previously reported inverse association between coffee and tea consumption and kidney stones (8,9). Coffee and tea are sources of caffeine, which has been reported to increase diuresis moderately together with the excretion of magnesium and potassium as well as calcium and sodium (25). More recent evidence suggests that caffeine-induced natriuresis might be caused by the action on both the proximal and distal tubules (26). Using an experimental model, Ming and Lautt (27) also suggested that the diuretic and natriuretic effect of caffeine, an inhibitor of adenosine receptors, might be explained by interfering with the hepatorenal reflex mediated by hepatic A_1 adenosin receptors. However, the reduced risk of stones associated with the increased intake of decaffeinated coffee found in our study suggests that other mechanisms may be involved, possibly related to the presence in caffeinated and decaffeinated coffee and tea of phytochemicals with potent antioxidant properties such as chlorogenic acids (28,29).

We observed a reduced risk of stones in individuals who consumed higher amounts of wine and beer consistently with our previous report (8,9). Alcohol ingestion is associated with a diuresis; although some evidence exists that alcohol intake may reduce circulating levels of antidiuretic hormone with subsequent urine dilution (30,31), these findings were not confirmed in other studies (32–34). The mechanism of alcohol-induced diuresis remains to be elucidated.

We found an inverse association between consumption of orange juice and development of stones. Orange juice is rich in potassium citrate, and it favorably affects urine composition and risk of stone formation by increasing citraturia, delivering an alkali load comparable with the load obtained by administering potassium citrate (35,36). Orange juice is also rich in fructose; however, the beneficial effects of citrate might offset the calciuric or other effects of fructose compared with other juices that are comparably richer in fructose than citrate (*e.g.*, apple juice).

Compared with the previously published analysis, we did not confirm the finding of a significantly higher risk of kidney stones in participants consuming higher amounts of apple juice (8) or grapefruit juice (8,9). The previous findings might have been because of the relatively smaller number of cases in the previous analyses. We report a new association between consumption of punch and development of kidney stones. Punch, as well as sugar-sweetened soda, is rich in fructose, and this reason might explain the association with kidney stones.

Our study has several strengths. It was a prospective analysis of three large and well characterized cohorts, each with over 16 years of follow-up. We used validated exposures and outcomes and were able to adjust our estimates for a large number of potential confounders. We calculated and reported pooled estimates incorporating random effects to account for within-cohort variability.

Our study also has limitations. We could not analyze the associations with different stone compositions; however, 80% of the kidney stones in the general population are made of calcium oxalate (37). We had only limited data on urinary composition, which would be useful to explain the biologic effect of specific beverages on kidney stone formation. We could not, based on the items on the questionnaire, separate caffeinated and noncaffeinated sodas effectively. Also, we did not have access to the coffee brand, which could arguably influence the amount of caffeine. Moreover, the vast majority of the participants were white, and therefore, it is unclear if the findings apply to other racial groups. Finally, we did not measure nutrient intakes exactly but relied on information from a validated FFQ.

In conclusion, our prospective study confirms that some beverages are inversely associated with kidney stone formation, whereas others are associated with a higher risk. Although higher total fluid intake reduces the risk of stone formation, information about the associations for individual beverages may be useful for general practitioners and nephrologists seeking to implement strategies to reduce the risk of stone formation in their patients.

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Disclosures

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