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Prospective Study of Beverage Use and the Risk of Kidney Stones

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Patients with kidney stones are routinely advised to increase their fluid intake to decrease the risk of stone recurrence. However, there has been no detailed examination to determine whether the effect on recurrence varies by the type of beverage consumed. The authors conducted a prospective study of the relation between the intake of 21 different beverages and the risk of symptomatic kidney stones in a cohort of 45,289 men, 40–75 years of age, who had no history of kidney stones. Beverage use and other dietary information was measured by means of a semiquantitative food frequency questionnaire in 1986. During 6 years of follow-up (242,100 person-years), 753 incident cases of kidney stones were documented. After adjusting simultaneously for age, dietary intake of calcium, animal protein and potassium, thiazide use, geographic region, profession, and total fluid intake, consumption of specific beverages significantly added to the prediction of kidney stone risk ($p < 0.001$). After mutually adjusting for the intake of other beverages, the risk of stone formation decreased by the following amount for each 240-ml (8-oz) serving consumed daily: caffeinated coffee, 10% (95% confidence interval 4–15%); decaffeinated coffee, 10% (3–16%); tea, 14% (5–22%); beer, 21% (12–30%); and wine, 39% (10–58%). For each 240-ml serving consumed daily, the risk of stone formation increased by 35% (4–75%) for apple juice and 37% (1–85%) for grapefruit juice. The authors conclude that beverage type may have an effect on stone formation that involves more than additional fluid intake alone. *Am J Epidemiol* 1996;143:240–7.

beverages; epidemiologic factors; kidney calculi; prospective studies

Kidney stones are a common, painful, and costly medical condition. Approximately 12 percent of the US population will form a stone at some time (1, 2). Recurrences are common with 30–50 percent of men forming another stone within 5 years of the incident stone (2–4). To decrease the likelihood of stone recurrence, patients are routinely advised to increase their urine volume by increasing their fluid intake. Increasing fluid intake is not a proven remedy; however, most authors (5–8) support this recommendation, even though some (9) do not.

Although the effects of particular beverages on changes in urine composition have been studied, little information is available on changes in stone formation rates. Using a retrospective case-control design to examine the relation between the intake of six beverages and a history of kidney stones, Shuster et al. (10) observed an inverse association for beer and coffee consumption and a direct association for carbonated beverage (soda) consumption. No associations were found for milk, tea, or water. Other risk factors for kidney stones, such as other dietary variables (11), were not controlled for in the analysis. This study was followed by a randomized trial of decreasing soft drink use on the risk of stone recurrence (12). A significant decrease of 6.4 percent in the stone recurrence rate was observed in the group advised to avoid soda consumption.

We have previously shown an inverse association between total fluid intake and the risk of stone formation in a prospective cohort study of 45,619 US men (11). To investigate whether the type of fluid ingested is important, we examined the relation between the use of 21 specific beverages and the risk of symptomatic kidney stones.

METHODS

Population

The Health Professionals Follow-up Study is a longitudinal study of cancer and cardiovascular and other

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diseases among 51,529 male dentists, optometrists, osteopaths, pharmacists, podiatrists, and veterinarians who were 40–75 years old in 1986. The participants returned a mailed questionnaire in 1986 concerning diet, medical history, and medications. Of the 49,999 participants who provided complete information on diet, we excluded 3,965 men (7.9 percent) who reported a history of kidney stones prior to 1986 because they might have changed their fluid intake as a consequence of the kidney stone. The prevalence at baseline ranged from 5.3 percent in the men younger than 45 years to 10.0 percent in those 70 years and older.

Assessment of diet

We assessed the men's diets using a semiquantitative food frequency questionnaire that contained inquiries about the average use of 131 food items, including 21 beverages, during the previous year. We computed nutrient intakes from the reported frequency of consumption of each food or beverage using published data on the nutrient content of the specified portions (13). We also collected information on the amount of supplemental calcium (e.g., calcium carbonate) intake, either alone or in multivitamin preparations. We previously reported on the reproducibility and validity of this dietary questionnaire in this cohort (14).

Study participants reported specific beverage use as the number of times a standard serving size was consumed, with nine frequency categories ranging from less than once per month to six or more times per day. The beverages included in the questionnaire are listed in table 1. The average daily intake of each beverage was calculated by multiplying the reported frequency of use by the serving size for the beverage. Red and white wine were combined into a single variable (wine) because there was no a priori hypothesis that the individual types of wine would have a differential effect on the risk of stone formation. Reasonable levels of reproducibility and validity were observed for

TABLE 1. Distribution (%) of beverage use among 45,289 men with no history of kidney stones at baseline in 1986,* Health Professionals Follow-up Study

Beverage (serving size†)	Frequency of use (%)									
	<1/ month	1–3/ months	1/ week	2–4/ weeks	5–6/ weeks	1/day	2–3/ days	4–5/ days	≥6/ days	Missing
Water (1 glass)	2.7	2.3	2.5	5.7	4.8	17.7	33.7	19.9	10.3	0.5
Milk (8-oz glass)										
Skim/low fat	24.3	7.9	5.3	17.3	9.1	17.5	13.2	1.3	0.5	3.5
Whole	65.5	8.7	3.4	5.5	1.8	3.3	2.0	0.3	0.1	9.4
Juices (small glass)										
Apple	47.2	24.7	10.8	8.0	1.7	1.7	0.5	0.1	0.03	5.3
Orange	16.1	17.1	11.7	18.6	8.8	21.1	2.7	0.3	0.3	3.3
Grapefruit	64.0	15.8	5.6	4.6	1.1	1.5	0.4	0.1	0.02	7.1
Other fruit	49.2	22.6	9.4	7.5	1.7	2.4	0.4	0.04	0.04	6.6
Tomato	52.9	26.9	10.0	4.7	1.0	1.1	0.1	0.01	0.01	3.3
Punch/lemonade (1 glass)	64.6	16.8	7.4	4.4	1.2	1.2	0.4	0.1	0.01	3.9
Sodas (1 can)										
Cola, with caffeine	54.5	16.6	9.9	9.6	2.7	2.7	1.2	0.1	0.04	2.6
Cola, without caffeine	76.7	9.8	4.8	2.6	0.5	0.5	0.2	0.01	0.004	4.9
Cola, diet, with caffeine	61.4	10.8	6.4	8.3	2.9	3.9	2.6	0.4	0.1	3.2
Cola, diet, without caffeine	60.1	12.1	7.6	8.6	2.5	3.5	1.8	0.2	0.1	3.4
Noncola	62.1	18.6	9.3	5.2	0.8	0.8	0.3	0.01	0.002	2.9
Noncola, diet	58.9	15.0	8.8	7.6	1.9	2.1	0.8	0.1	0.04	4.7
Coffee/tea (1 cup)										
Coffee, caffeinated	28.9	5.7	4.3	7.2	4.7	13.1	22.9	8.1	2.8	2.4
Coffee, decaffeinated	44.9	9.3	5.5	8.5	4.7	9.3	11.1	2.8	0.8	3.1
Tea	40.7	15.2	9.1	10.5	4.6	9.0	6.3	1.1	0.3	3.2
Alcoholic beverages										
Beer (1 can)	42.4	17.9	11.4	14.1	4.1	4.3	3.2	0.6	0.2	1.8
Wine (4-oz glass)	39.1	11.6	20.4	12.3	8.4	2.7	2.3	0.4	0.4	2.3
Liquor (1 shot)	46.1	15.7	8.4	12.2	4.7	5.1	5.6	0.7	0.2	1.2

* Values are percentage of cohort reporting the particular category of use. Total percentage may not add up to exactly 100 due to rounding.
† Serving sizes are consistent with the exact wording of the food frequency questionnaire.

reported intake of individual beverages using the semiquantitative food frequency questionnaire (15). Pearson correlations between the food records and the questionnaire ranged from 0.52 for plain water to 0.93 for coffee, with a mean correlation of 0.77.

We calculated daily total fluid intake from beverages by using data on frequency of use and serving size of the individual beverages. The data consist of reported fluid intake but not urine volumes. However, as part of the diet validation study (14), we collected 24-hour urine samples and found a high correlation ($r = 0.59$) between reported fluid intake and 24-hour urine volume (unpublished data).

Nutrient values were adjusted for total energy intake using a regression model with total caloric intake as the independent variable and absolute nutrient intake as the dependent variable (16, 17). As total energy intake for an individual tends to be fixed in a very narrow range, changes in nutrient intake must be made primarily by altering the composition of the diet, not the total amount of food consumed. Energy-adjusted values reflect the nutrient composition of the diet independent of the total amount of food consumed. In addition, energy adjustment reduces any variation introduced by underreporting or overreporting of intake on the food frequency questionnaire, thus improving the accuracy of nutrient measurement (14). Beverage intake was not adjusted for total energy intake.

Assessment of nondietary factors

In 1986, participants provided information on their state of residence, weight, height, and use of thiazide diuretics. The level of physical activity in metabolic equivalents per week was computed from the reported frequency and duration of various forms of mild to vigorous exercise.

Follow-up and case ascertainment

We sent follow-up questionnaires in 1988, 1990, and 1992, asking the participants whether they had had a kidney stone diagnosed since January 1986. After up to six mailings for each follow-up period (18), the response rate was greater than 94 percent.

When a kidney stone was reported on a follow-up questionnaire, we mailed a supplementary form to confirm the self-report and to ascertain the date of occurrence, symptoms, and family history of kidney stones. The rate of response to the supplementary questionnaire was 93 percent. The primary end point was an incident kidney stone accompanied by pain or hematuria. To confirm the validity of the self-report, we obtained the medical records from a random sample of 60 cases. All were confirmed except two, which were bladder stones.

We considered only cases that occurred during the first 6 years of follow-up—between the return of the 1986 baseline questionnaire and January 31, 1992. After excluding men who lived outside the US and men for whom the stone could not be confirmed or the occurrence was outside the study period, 45,289 men with no history of kidney stones at baseline remained.

Statistical analysis

For each participant, the person-months of follow-up were counted from the return date of the 1986 questionnaire to the date of a kidney stone or death, or January 31, 1992, whichever came first. We allocated person-months of follow-up according to the 1986 exposure status and calculated incidence as the number of events divided by the person-time of follow-up. The proportion of subjects with missing information for any individual beverage was less than 10 percent (table 1). These subjects were assigned to the lowest category of intake for that beverage because in the validation study, we found that a missing item was not consumed at all in the majority of instances. The categories for all items on the food frequency questionnaire, not just the beverages, were selected in 1988 based on the frequency response for each individual item. The goal was to have a sufficient number of participants in each category, particularly the extreme categories, to provide sufficient power to examine associations in subjects with extreme intake. For the beverage analyses, we did look at the nine individual response categories after examining the grouped categories to determine whether substantial variation was being masked. Because the results were very similar, the a priori selected grouped categories were used to provide more stable estimates of the associations. The relative risk—the incidence rate in a particular category of beverage use divided by the corresponding rate in the comparison category—was used as the measure of association (19).

We formally tested the null hypothesis that beverage type did not influence risk of kidney stones by adding intake of all specific beverages (except for water) to a multiple logistic model containing total fluid intake and evaluating the change in total model deviance (likelihood ratio test) with 20 df. Clinically, patients with kidney stones are frequently advised to drink a certain number of 240-ml (8-oz) glasses of liquid each day to produce at least 2 liters of urine. Therefore, for the multivariate model, we converted the daily use of each beverage into the number (or fraction) of 240-ml servings consumed per day. This provides an estimation of the effect on the risk of stone formation of increasing the consumption by one unit (240 ml) of an individual beverage. Relative risks for specific beverages were adjusted simultaneously for other stone risk factors (11) using similar multiple logistic models (20). Variables considered in the multivariate models were specific beverage use (240-ml portions per day), age (5-year categories), quintiles of body mass index (weight in kilograms divided by the square of the height in meters), quartiles of physical activity level, geographic region (seven categories), subject's specific health profession, use of thiazide diuretics (yes/no), and quintiles of dietary intake of calcium, animal protein, and potassium. We previously showed that these dietary variables are related to risk of kidney stones (11). For all relative risks, we calculated 95 percent confidence intervals; all p values are two tailed.

RESULTS

The frequency of use of the individual beverages by the cohort members as reported on the baseline questionnaire is shown in table 1. During 242,100 person-years of follow-up over a 6-year period, 753 cases of incident symptomatic kidney stones were documented. After controlling for potential confounding by other risk factors, the relative risk of stone formation for men in the highest quintile of total fluid intake (≥2,538 ml/day) compared with the lowest quintile (<1,275 ml/day) was 0.65 (95 percent confidence interval 0.51–0.84).

After we controlled simultaneously for potential confounding by other risk factors including age, profession, geographic region, thiazide use, intake of dietary calcium, potassium, and animal protein, and total fluid, we found that the addition of specific beverages contributed significantly to the prediction of kidney stones (change in −2 log likelihood = 72.9 with 20 df, $p < 0.001$). In an additional model including all specific beverages but not total fluid intake, significant inverse associations were observed for caffeinated coffee, decaffeinated coffee, tea, beer, and wine (table 2). Apple juice and grapefruit juice were directly associated with risk (table 2).

For each 240-ml serving consumed daily, the risk of stone formation decreased by the following amount for the stated beverage when analyzed as a continuous variable: caffeinated coffee, 10 percent (95 percent confidence interval 4–15 percent); decaffeinated coffee, 10 percent (3–16 percent); tea, 14 percent (5–22 percent); beer, 21 percent (12–30 percent); and wine, 39 percent (10–58 percent). For each 240-ml portion consumed daily, the risk of stone formation increased by 35 percent (95 percent confidence interval 4–75 percent) for apple juice and 37 percent (1–85 percent) for grapefruit juice.

The risk of stone formation was examined according to category of consumption of the beverages for which we observed an overall association. In table 3, the multivariate relative risks are presented by frequency of beverage consumption using the standard serving size for each beverage (see table 1). The risk of stone formation decreased with increasing frequency of use of caffeinated and decaffeinated coffee, tea, beer, and

TABLE 2. Age-adjusted and multivariate relative risk of incident kidney stones for individual beverages per 240-ml (8-oz) serving size per day, Health Professionals Follow-up Study, 1986

Beverage	Age-adjusted		Multivariate*	
	RR†	95% CI†	RR	95% CI
Water	0.96	0.92–1.00	0.97	0.93–1.02
Milk				
Skim/low fat	0.89	0.82–0.96	0.97	0.85–1.10
Whole	0.86	0.72–1.02	0.87	0.71–1.05
Juices				
Apple	1.23	0.95–1.60	1.35	1.04–1.75
Orange	0.82	0.67–1.01	0.94	0.76–1.16
Grapefruit	1.19	0.87–1.61	1.37	1.01–1.85
Other fruit	0.80	0.49–1.32	0.83	0.50–1.36
Tomato	1.06	0.57–1.97	1.41	0.76–2.63
Punch/lemonade	1.14	1.01–1.30	1.11	0.97–1.27
Sodas				
Cola, with caffeine	1.11	1.01–1.22	1.06	0.96–1.18
Cola, without caffeine	0.98	0.75–1.29	0.93	0.70–1.23
Cola, diet, with caffeine	0.93	0.85–1.02	0.93	0.85–1.02
Cola, diet, without caffeine	1.01	0.92–1.12	1.02	0.92–1.12
Noncola	1.09	0.88–1.35	1.02	0.81–1.28
Noncola, diet	1.09	0.97–1.23	1.11	0.98–1.26
Coffee/tea				
Coffee, caffeinated	0.87	0.83–0.92	0.90	0.85–0.96
Coffee, decaffeinated	0.90	0.84–0.97	0.90	0.84–0.97
Tea	0.85	0.77–0.94	0.86	0.78–0.95
Alcoholic beverages				
Beer	0.80	0.72–0.90	0.79	0.70–0.88
Wine	0.60	0.40–0.88	0.61	0.42–0.90
Liquor	0.94	0.52–1.70	0.72	0.39–1.33

* The multivariate model included age (in 5-year categories), profession, geographic region (seven categories), use of thiazide diuretics (yes/no), dietary intake of calcium, animal protein, and potassium (quintile groups), and all 21 beverages (continuous variables with each unit representing 240 ml (8 oz) per day of that beverage).

† RR, relative risk; CI, confidence interval.

TABLE 3. Multivariate relative risks for beverages associated with the incidence of symptomatic kidney stones,* Health Professionals Follow-up Study

<table>
<tr><th rowspan="2">Beverage</th><th colspan="9">Frequency of use</th></tr>
<tr><th><1/ month</th><th>1–3/ month</th><th>1/ week</th><th>2–4/ week</th><th>5–6/ week</th><th>1/day</th><th>2–3/ day</th><th>4–5/ day</th><th>≥6/day</th></tr>
<tr><td>Caffeinated coffee</td><td></td><td colspan="5"></td><td></td><td colspan="2"></td></tr>
<tr><td>Cases</td><td>281</td><td colspan="5">270</td><td>156</td><td colspan="2">46</td></tr>
<tr><td>Person-years</td><td>75,477</td><td colspan="5">84,607</td><td>55,539</td><td colspan="2">26,477</td></tr>
<tr><td>Multivariate RR†</td><td>1.0</td><td colspan="5">0.89</td><td>0.80</td><td colspan="2">0.54</td></tr>
<tr><td>95% CI†</td><td></td><td colspan="5">0.74–1.06</td><td>0.64–0.99</td><td colspan="2">0.38–0.75</td></tr>
<tr><td>Decaffeinated coffee</td><td></td><td colspan="5"></td><td></td><td colspan="2"></td></tr>
<tr><td>Cases</td><td>397</td><td colspan="5">269</td><td>64</td><td colspan="2">23</td></tr>
<tr><td>Person-years</td><td>116,236</td><td colspan="5">90,366</td><td>26,927</td><td colspan="2">8,570</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td colspan="5">0.88</td><td>0.68</td><td colspan="2">0.77</td></tr>
<tr><td>95% CI</td><td></td><td colspan="5">0.74–1.04</td><td>0.51–0.89</td><td colspan="2">0.50–1.19</td></tr>
<tr><td>Tea</td><td></td><td colspan="5"></td><td></td><td colspan="2"></td></tr>
<tr><td>Cases</td><td>328</td><td colspan="5">385</td><td>34</td><td colspan="2">6</td></tr>
<tr><td>Person-years</td><td>105,884</td><td colspan="5">117,377</td><td>15,293</td><td colspan="2">3,546</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td colspan="5">1.01</td><td>0.65</td><td colspan="2">0.53</td></tr>
<tr><td>95% CI</td><td></td><td colspan="5">0.87–1.18</td><td>0.45–0.93</td><td colspan="2">0.23–1.19</td></tr>
<tr><td>Beer</td><td></td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td>Cases</td><td>355</td><td>129</td><td colspan="2">202</td><td colspan="2">60</td><td colspan="3">7</td></tr>
<tr><td>Person-years</td><td>106,589</td><td>43,343</td><td colspan="2">61,866</td><td colspan="2">20,445</td><td colspan="3">9,857</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td>0.91</td><td colspan="2">1.01</td><td colspan="2">0.91</td><td colspan="3">0.22</td></tr>
<tr><td>95% CI</td><td></td><td>0.73–1.14</td><td colspan="2">0.83–1.25</td><td colspan="2">0.68–1.22</td><td colspan="3">0.10–0.46</td></tr>
<tr><td>Wine</td><td></td><td></td><td></td><td></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td>Cases</td><td>332</td><td>95</td><td>156</td><td>85</td><td colspan="2">74</td><td colspan="3">11</td></tr>
<tr><td>Person-years</td><td>99,609</td><td>28,129</td><td>49,630</td><td>29,956</td><td colspan="2">27,216</td><td colspan="3">7,559</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td>0.99</td><td>0.90</td><td>0.86</td><td colspan="2">0.86</td><td colspan="3">0.50</td></tr>
<tr><td>95% CI</td><td></td><td>0.77–1.26</td><td>0.73–1.12</td><td>0.66–1.12</td><td colspan="2">0.65–1.13</td><td colspan="3">0.27–0.92</td></tr>
<tr><td>Apple juice</td><td></td><td></td><td></td><td></td><td colspan="5"></td></tr>
<tr><td>Cases</td><td>374</td><td>175</td><td>88</td><td>79</td><td colspan="5">37</td></tr>
<tr><td>Person-years</td><td>126,965</td><td>60,154</td><td>26,286</td><td>19,320</td><td colspan="5">9,375</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td>0.83</td><td>0.93</td><td>1.18</td><td colspan="5">1.29</td></tr>
<tr><td>95% CI</td><td></td><td>0.68–1.01</td><td>0.72–1.20</td><td>0.91–1.54</td><td colspan="5">0.90–1.84</td></tr>
<tr><td>Grapefruit juice</td><td></td><td></td><td></td><td></td><td colspan="5"></td></tr>
<tr><td>Cases</td><td>504</td><td>136</td><td>48</td><td>40</td><td colspan="5">25</td></tr>
<tr><td>Person-years</td><td>171,996</td><td>38,175</td><td>13,500</td><td>10,997</td><td colspan="5">7,431</td></tr>
<tr><td>Multivariate RR</td><td>1.0</td><td>1.20</td><td>1.26</td><td>1.30</td><td colspan="5">1.40</td></tr>
<tr><td>95% CI</td><td></td><td>0.98–1.48</td><td>0.92–1.73</td><td>0.93–1.82</td><td colspan="5">0.93–2.12</td></tr>
</table>

* The multivariate model included age (in 5-year age categories), profession, geographic region (seven categories), use of thiazide diuretics (yes/no), dietary intake of calcium, animal protein, and potassium (quintile groups), and all 21 beverages (continuous variables with each unit representing 240 ml (8 oz) per day of that beverage).

† RR, relative risk; CI, confidence interval.

wine. The risk increased with increasing use of apple juice and grapefruit juice.

We also compared the risk of kidney stones associated with specific beverages with that of water, a presumably neutral fluid, to control for a similar volume of intake. Caffeinated coffee ($p = 0.03$), tea ($p = 0.02$), beer ($p = 0.001$), and wine ($p = 0.02$) were inversely associated with risk and were significantly different from water; decaffeinated coffee was marginally significant ($p = 0.07$). Apple juice ($p = 0.02$) and grapefruit juice ($p = 0.03$) were directly associated with risk and significantly different from water.

DISCUSSION

These prospective data confirm that greater fluid intake is associated with reduced risk of kidney stones, further suggesting that greater consumption of caffeinated and decaffeinated coffee, tea, beer, and wine decreases the risk of symptomatic kidney stones whereas greater consumption of apple and grapefruit juice increases the risk. The overall risk from beverages depends on the risk of consuming the specific beverage. Although we do not know the composition of the stones formed, the vast majority of stones in this group of men will contain calcium oxalate (2, 21).

The urinary concentration of lithogenic factors and risk of crystal formation can be lowered simply by increasing urine volume (6). In the steady state in healthy individuals, fluid intake is the main determinant of urine volume. Thus, patients who have formed kidney stones are routinely advised to increase their fluid intake. However, information on the effect of different beverages on risk of stone occurrence is sparse. The effects of specific beverages, such as orange juice (22) and sugared cola (23), have been examined in relation to changes in the urine composition but not to stone formation. The effects on stone formation of water hardness (24, 25) and primary fluid intake (10) have been studied using retrospective designs; however, these studies failed to address the important role of other dietary factors (11).

The mechanism for the protective effect of caffeinated coffee and tea may be mediated through caffeine. Caffeine interferes with the action of antidiuretic hormone on the distal nephron (26) resulting in increased urine flow and a more dilute urine, which would lower the risk of crystal formation. However, this beneficial effect may be partly offset by the increase in urinary calcium excretion caused by caffeine (27). The protective effect of beer and wine may be due to the inhibitory effect of alcohol on antidiuretic hormone secretion (26) with increased urine flow and decreased urinary concentration. A similar magnitude of association was seen for liquor; however, the confidence interval was wide.

The inverse association for tea and coffee may seem surprising given the common belief that these beverages, particularly tea, have significant amounts of oxalate. Very little information on the oxalate content of foods and beverages is available. Kasidas and Rose (28), using foods bought in England and an enzymatic method to measure oxalate content, found that a 240-ml portion of tea contained 17 mg of oxalate and a 240-ml serving of instant coffee contained 8 mg of oxalate. Thus, it appears that the amount of oxalate contributed to the diet by these beverages, although not trivial, is probably small.

It is unclear why decaffeinated coffee was associated with a decreased risk. It is possible that for those beverages inversely associated with risk, it was simply the fluid intake that was protective; however, we did not observe similar protection from all beverages at a similar volume of intake. Because we examined a large number of beverages, the possibility exists that some associations may have occurred by chance. Although the data are internally consistent for major sources of caffeine and alcohol, the findings for decaffeinated coffee clearly require confirmation.

The mechanism for the increased risk associated with apple and grapefruit juice consumption is also not obvious. Although the pH of these beverages is acidic (~3.5) (29), the actual total acid load is small. The oxalate content of these beverages has been reported to be less than 1 mg/liter (28). These beverages do contain a substantial amount of sugar, which can increase calcium excretion (30). However, other acidic beverages containing considerably more sugar, such as punch and lemonade and soda, were not associated with increased risk. Additional data from extended follow-up and other populations are required to confirm or refute the associations with these fruit juices.

Shuster et al. (12) studied the relation between soft drink consumption and the risk of kidney stone recurrence. The study population consisted of 1,009 male subjects with incident or recurrent stone disease who drank at least one-half can of soda per day. Of the randomly selected subjects advised to avoid soda consumption, 170/504 (64.6 percent) remained free of recurrence at 3 years. Of the other half of subjects who were given no special instructions regarding soda use, 205/505 (58.2 percent) were free of recurrence at 3 years ($p = 0.05$). In a subanalysis, the beneficial effect of abstaining from soda was limited to those whose most consumed soda was acidified by phosphoric but not citric acid; no clear mechanism was proposed. The patients were managed by their primary urologist; however, information on therapeutic interventions and beverages consumed instead of soda was not available. Thus, the reduction in recurrence among the participants given special dietary instructions may have been due to the increase in a beverage type other than soda.

After we adjusted for age alone, it appeared that the consumption of caffeinated sugared cola was associated with increased risk (table 2), which is consistent with previous reports (10, 12). However, after controlling for other potential risk factors, the association was no longer significant for sugared cola or for the other types of soda (table 2). The intake of caffeinated sugared cola was inversely correlated with dietary calcium (correlation coefficient = −0.14, $p < 0.001$) and dietary potassium (correlation coefficient = −0.28, $p < 0.001$). We have previously reported that the risk of stone formation decreases with increased intake of dietary calcium and potassium (11). Thus, it appears that the results of these previous studies on soda consumption may have been confounded by other dietary factors. Furthermore, the previously mentioned randomized trial evaluating the role of soda on stone recurrence failed to account for other beverages that were consumed in the test group in place of soda. If the test subjects changed from caffeinated sugared cola to caffeinated coffee, for example, a decrease in the recurrence rate may have occurred due to the protective effect of coffee rather than to a stone-promoting effect of sugared colas.

The presence or lack of association between a beverage and risk of stone formation could be a result of substantial correlation between the use of specific beverages or total volume. Although correlations between beverages in the multivariate model would not on average affect the relative risks, they could widen the confidence intervals. The greatest correlation (r = 0.43) was between sugared colas and sugared noncolas; most other correlations were less than 0.20 (data not shown). Although beer (r = 0.32) and caffeinated coffee (r = 0.40) were moderately correlated with total fluid intake, other beverages such as water (r = 0.48) with similar or larger correlation coefficients were not significantly associated with a reduced risk of stone formation.

Biased recall of diet was avoided in this study because the intake data were collected before the diagnosis of kidney stones was made. However, nondietary risk factors for kidney stones could have influenced our results if they were strongly associated with the use of certain beverages.

These findings were observed among men ages 40 years and older with no history of kidney stones. In our cohort, more than 50 percent of the men were younger than age 60 at baseline; only 8 percent had a history of kidney stones and were therefore excluded. With the information currently available in the literature, we have no reason to believe that the relations we observed would be different in women, younger men, or men with a history of kidney stones containing calcium oxalate.

Our findings suggest that the effect of beverages on stone formation involves more than increasing fluid intake. In this study, greater intakes of caffeinated and decaffeinated coffee, tea, beer, and wine were associated with a decreased risk of stone formation, whereas greater intakes of apple and grapefruit juice were related to increased risk. Before definitive recommendations can be given to patients who have had kidney stones, additional studies are needed.

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