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Relation between Geographic Variability in Kidney Stones Prevalence and Risk Factors for Stones

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To determine whether geographic variability in rates of kidney stones in the United States was attributable to differences in personal and environmental exposures, the authors examined cross-sectional data that included information on self-reported, physician-diagnosed kidney stones collected from 1,167,009 men and women, aged ≥30 years, recruited nationally in 1982. Information on risk factors for stones including age, race, education, body mass, hypertension, and diuretic and vitamin C supplement use was obtained by self-administered questionnaire. Consumption of milk, coffee, tea, soft drinks, and alcohol was based on food frequency data. Indices of ambient temperature and sunlight level were assigned to subjects based on state of residence. Stones were nearly twice as prevalent in the Southeast as in the Northwest among men and women. Ambient temperature and sunlight indices were independently associated with stones prevalence after controlling for other risk factors for stones. Regional variation was eliminated for men and greatly reduced for women after adjustment for temperature, sunlight, and beverage consumption. Other factors appeared to not contribute to regional variation. These results provide evidence that ambient temperature and sunlight levels are important risk factors for stones and that differences in exposure to temperature and sunlight and beverages may contribute to geographic variability. *Am J Epidemiol* 1996;143:487–95.

geography; kidney calculi; risk factors; urolithiasis

Geographic variation in the rates of kidney stones has been observed for many years. Rates of hospitalization for stones vary considerably not only among countries, with higher rates in industrialized nations compared with developing and Third World countries (1), but also regionally within countries (2–6). Based largely on ecologic observations, some investigators contend that differences in dietary protein (5, 7) or refined carbohydrate intake (8) provide the most likely explanation for these contrasts. Others have suggested that the differences may be due to variations in climate (9), water quality (10–14), or the prevalence of comorbid conditions that may affect the risk of stones (15).

We found in a study of stones in a large US cohort (15) that the lifetime prevalence of stones was higher among men and women who lived in southern latitudes compared with men and women in northern latitudes. Based on these observations, we hypothesized that the north-south gradient of increasing kidney stone prevalence was the result of differences in ambient temperature and perhaps sunlight exposure.

The purpose of the present study was to extend the analyses of data obtained from this cohort to: 1) examine relations between stones prevalence and ecologic measures of both ambient air temperature and sunlight levels; and 2) determine the extent to which statistical adjustment for regional differences in air temperature, sunlight levels, and personal risk factors for stones explain geographic variability of stones prevalence.

MATERIALS AND METHODS

Study population

In the fall of 1982, 1,185,124 people aged 30 years or older completed a self-administered questionnaire on disease history, medication use, diet, and other health-related matters in the Second Cancer Prevention Survey (CPS II), described elsewhere (16). Participants in this cross-sectional study were friends,

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Abbreviations: BMI, body mass index; CI, confidence interval; CPS II, Second Cancer Prevention Survey; OR, odds ratio; RR, relative risk.

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relatives, and neighbors of more than 70,000 American Cancer Society volunteers who lived in all 50 US states, the District of Columbia, and Puerto Rico.

Participants in CPS II were largely middle aged, well educated, and white. Overall, the lifetime prevalence of stones was 8.8 percent among men and 3.3 percent among women.

Data collection

Participants who reported having been diagnosed with kidney stones at any time during their lives by a physician were considered prevalent cases. Participants provided their age at enrollment, their education level, and their race or ethnicity, specified as either white, black, Hispanic, or Asian. Self-reported weight and height were used to calculate body mass index (BMI). Respondents who reported a history of high blood pressure were considered to have hypertension. Information was also collected on the use of medications including antihypertensives, diuretics, and vitamin C supplements. Consumption of beverages, including milk, coffee, tea, soft drinks, and alcohol, was assessed with the use of a food frequency questionnaire.

All states in the continental United States were divided by the combination of latitude and longitude into seven geographic regions (see Appendix). CPS II participants were categorized into one of these regions according to the state in which they resided at the time of questionnaire completion.

We used two indices of environmental exposure. The first used the average annual temperatures of the major weather reporting cities in each state to assign an annual average ambient temperature for that state (17). The second measure was an index of annual sunlight level based on estimated ultraviolet radiation levels for each state (18). The sunlight index is an estimate of annual ultraviolet radiation over the range of latitudes encompassed by a state in relation to annual cloud cover measurements for that state and is indicative of potential sunlight exposure for people who lived in that state. Each person was assigned the exposure index value for the state in which he was a resident except in California where people who lived in northern and southern areas were assigned separate temperature indices (see Appendix table). Because CPS II participants were enrolled locally by volunteers who lived primarily in urban areas, the temperature indices we used were appropriate measures of potential exposure for the majority of study subjects.

Participants with missing information on age, race, and stones history (n = 10,263) and those who lived outside of the continental United States (n = 4,229) were excluded. The final study population included 501,025 men and 665,984 women.

Analysis

To describe the relations between personal risk factors and stones prevalence, we dichotomized exposures as follows: education beyond high school versus education through high school; overweight defined as a BMI at or above the 85 percentile of BMI measurements made on a probability sample of Americans (28.5, men; 28.3, women) (19) versus not overweight; hypertension versus no hypertension; diuretic use versus non-use; vitamin C supplement use versus non-use; and any intake of tea, soft drinks, milk, coffee, and alcohol versus no intake. To examine the relations between temperature and sunlight indices and stones prevalence, five categories of exposure were defined using quintile cutpoints.

For each exposure level, the odds of ever having had a kidney stone divided by the odds in a reference exposure category (lifetime prevalence odds ratio) was determined (20). Levels indicative of the least exposure to personal and environmental exposures were used as the reference categories in these analyses.

We examined whether the relations between temperature and sunlight indices and stones were confounded by personal risk factors for stones with the use of logistic regression (21, 22). In all regression analyses, the outcome variable was previous diagnosis with kidney stones by a physician (yes or no). Factors entered into regression models using categorical indicator variables included: age (5-year groups), race (black, Asian, or Hispanic), six levels of education, four levels of body mass index, untreated and treated hypertension, diuretic use, four levels of vitamin C supplement use, four levels of exposure to alcohol, diet drinks, and non-diet colas, and five levels of exposure to milk, coffee, and tea. Significant interaction terms, identified using log-likelihood ratio tests (23), were included in all regression models that contained the relevant component factors. Confidence intervals for the odds ratio estimates were calculated using the standard error of the regression coefficients.

To examine age-adjusted variations in the distribution of environmental and personal risk factors across regions, we used analysis of covariance (22, 24). Average values of body mass index, beverage intake, ambient temperature, and sunlight index for each region were compared. Regional comparisons of education and vitamin C supplementation used the least squares mean of the ordinally ranked exposure levels. There were seven levels of education ranging from 8th grade or less to graduate school (ranked 1–7) and five levels of vitamin C supplement use ranging from none to two or more tablets per day (ranked 1–5). Distributions of the proportion of persons who had hypertension or who took diuretics were examined using chi-square tests.

We tested for colinearity using a multiple linear regression model containing all independent variables and with a history of stones (coded 0 for no or 1 for yes) as the outcome (23). While the ambient temperature and sunlight indices were highly correlated (r = 0.9, men and women), the analysis indicated that no serious colinearity problem resulted when these factors were examined simultaneously in a multiple regression model.

To determine the extent to which adjustment for personal and environmental risk factors for stones could explain the regional variation in prevalence, we examined the lifetime prevalence odds ratio for each region relative to the Northwest, the region with the lowest prevalence of stones. Logistic regression was used to assess the influence of each of the risk factors on the association between region and stone prevalence. Factors that either alone or in combination with other factors resulted in a change in any of the regional odds of 0.1 or more were viewed as potential explanatory factors (confounders) of the relation between region and stone prevalence.

RESULTS

The regional distribution of men and women was similar; slightly more than half of the participants resided in the Midwest and Northeast regions of the country (table 1). After adjustment for age and race, the odds of ever having had kidney stones were greater among men and women who lived anywhere outside of the Northwest region, with odds increasing from west to east and from north to south. The odds of stones among participants who resided in the Southeast were nearly twice that of those living in the Northwest (odds ratio = 1.9, men and women).

Overweight, hypertension, diuretic use, and consumption of tea and soft drinks were each positively associated with stones among both men and women (table 1). In contrast, consumption of coffee, alcohol, and vitamin C supplements were negatively associated with stones. Education level was inversely associated with stones among women only. Among men, milk was negatively associated with stones prevalence.

The average annual temperature varied markedly among the states, ranging from 5.2°C (41°F) in North Dakota to 22°C (72°F) in Florida (see Appendix table). The sunlight index ranged from 14.6 in Washington state to 39.7 in Florida. As expected, states with higher annual temperatures also tended to have higher sunlight indices.

Among men and women, the prevalence of stones tended to increase as the average annual temperature increased, although there was a slight reduction at the highest temperature (table 2). The relation was somewhat stronger for men and persisted after adjustment for age and race. Simultaneous adjustment for personal risk factors for stones, including age, race, education, body mass index, the presence of hypertension, beverage consumption, and diuretic and vitamin C supplement use, revealed that very little of the relation between temperature and stones prevalence was due to differences in these factors (table 2).

A similar increase in stones prevalence was observed as the sunlight index rose (table 2). The increase in the odds of stones adjusted for age and race was observed among both men and women and, as with temperature, was little influenced by further adjustment for personal risk factors for stones.

Among factors positively associated with stones, high ambient temperature and sunlight levels, and the highest consumption of tea and colas were found in the Southeast (table 3). Further, low consumption of beverages negatively associated with stones including coffee and alcohol was also found in the Southeast. Although the exposure differences between regions were highly statistically significant ($p < 0.001$ in all cases), the magnitude of most of the differences was quite modest. However, the average temperature was 8°C (15°F) warmer and the average sunlight index was twice as high in the Southeast compared with the Northwest (table 3).

The regional odds of stones relative to the Northwest were reduced after accounting for several of the risk factors we studied (table 4). No changes in the age- and race-adjusted regional odds of stones were observed after accounting for education, body mass index, the presence of hypertension, or the use of diuretics or vitamin C supplements, either individually or as a group. However, individual adjustment for beverage intake, ambient temperature, and sunlight index each resulted in a decrease in the regional odds of stones. Among women, each of these factors accounted for a similar degree of regional variation, whereas, among men, sunlight index explained more of the variation in prevalence than beverage intake or temperature. After the simultaneous effects of all the studied risk factors that were considered, regional associations with stone prevalence were largely eliminated for men and markedly diminished among women.

DISCUSSION

Among the participants of a large volunteer survey, we found that ambient temperature and sunlight indi-

TABLE 1. Relations between geographic region of residence, personal risk factors, and history of kidney stones among US men and women aged ≥30 years recruited for the Second Cancer Prevention Survey, 1982

Risk factor	Men				Women			
	No.	% with stones	Odds ratio*	95% CI†	No.	% with stones	Odds ratio*	95% CI†
Region								
Northwest	18,166	7.0	1.0		23,670	2.5	1.0	
North Central	26,863	7.6	1.1	1.0–1.1	34,226	2.9	1.1	1.0–1.3
Midwest	132,685	7.9	1.1	1.1–1.2	173,987	3.1	1.2	1.1–1.4
Northeast	141,439	8.2	1.2	1.1–1.3	189,962	3.2	1.3	1.2–1.4
Southwest	62,935	8.6	1.2	1.2–1.3	82,620	3.2	1.3	1.2–1.4
South Central	38,073	9.3	1.4	1.3–1.5	49,877	3.2	1.3	1.2–1.4
Southeast	80,864	12.1	1.9	1.8–2.0	111,642	4.5	1.9	1.7–2.0
Education								
≤High school	178,361	9.1	1.0		291,824	3.7	1.0	
>High school	315,392	8.6	1.0	0.9–1.0	363,543	3.1	0.9	0.8–0.9
Overweight								
No	369,128	8.6	1.0		499,829	3.1	1.0	
Yes	121,002	9.4	1.1	1.1–1.2	151,068	4.1	1.3	1.3–1.4
Hypertension								
No	355,361	8.2	1.0		474,629	3.0	1.0	
Yes	145,664	10.2	1.2	1.2–1.3	191,355	4.2	1.4	1.3–1.4
Diuretic use								
No	458,400	8.6	1.0		584,846	3.2	1.0	
Yes	42,625	11.3	1.3	1.2–1.3	81,138	4.4	1.4	1.3–1.4
Vitamin C use								
No	387,510	8.9	1.0		486,457	3.4	1.0	
Yes	113,515	8.5	0.9	0.9–1.0	179,527	3.1	0.9	0.8–0.9
Tea								
None	262,692	7.8	1.0		272,431	3.1	1.0	
Any	219,981	10.0	1.3	1.3–1.3	361,570	3.5	1.1	1.1–1.1
Cola soft drinks								
None	356,784	8.5	1.0		504,445	3.3	1.0	
Any	125,889	9.8	1.3	1.2–1.3	129,556	3.6	1.2	1.1–1.2
Non-cola soft drinks								
None	416,868	8.7	1.0		554,989	3.3	1.0	
Any	65,805	9.7	1.2	1.1–1.2	79,012	3.4	1.1	1.0–1.1
Diet soft drinks								
None	373,814	8.7	1.0		406,212	3.3	1.0	
Any	108,859	9.4	1.1	1.1–1.1	227,789	3.4	1.1	1.0–1.1
Milk								
None	253,302	9.6	1.0		402,833	3.4	1.0	
Any	229,371	8.0	0.8	0.8–0.8	231,168	3.2	0.9	0.9–1.0
Coffee								
None	159,484	9.5	1.0		242,984	3.7	1.0	
Any	323,189	8.5	0.9	0.8–0.9	391,017	3.1	0.8	0.8–0.9
Alcohol								
None	216,351	10.1	1.0		383,262	3.6	1.0	
Any	266,322	7.8	0.8	0.7–0.8	250,739	2.9	0.8	0.7–0.8

* Odds ratios are adjusted for age and race.
† CI, confidence interval.

ces were independently associated with increased prevalence of stone disease. Further, the geographic variability of kidney stones in the United States was either eliminated or greatly reduced after controlling for the effects of personal and environmental exposures.

With few exceptions, warm climate has been found to be positively associated with stones (9, 25–33). Dehydration from inadequate fluid intake during exposure to high ambient temperatures increases the concentration and acidity of urine, which promotes stones (34, 35). In CPS II, higher temperature was positively associated with stone prevalence.

Among both men and women in CPS II, sunlight level increased the odds of stones. Parry and Lister (36) were the first to propose that exposure to sunlight might influence stone formation after they observed that urinary calcium levels increased among soldiers

TABLE 2. **Relations between mean annual temperature and sunlight index and history of kidney stones among US men and women aged ≥30 years recruited for the Second Cancer Prevention Survey, 1982**

Risk factor	No. of participants	Participants with stones		Crude* odds ratio	95% CI†	Adjusted‡ odds ratio	95% CI†
		No.	%				
Men							
Mean annual temperature (°C§)							
<9.9	78,250	5,448	7.0	1.0		1.0	
9.9–11.1	121,025	9,659	8.0	1.2	1.1–1.2	1.1	1.1–1.2
11.2–13.4	99,661	8,279	8.3	1.2	1.2–1.3	1.2	1.1–1.2
13.4–17.2	97,815	10,433	10.7	1.7	1.6–1.7	1.5	1.4–1.5
≥17.3	104,274	10,218	9.8	1.5	1.4–1.6	1.4	1.3–1.4
Sunlight index							
<19.9	57,827	3,883	6.7	1.0		1.0	
19.9–22.3	126,925	9,787	7.7	1.2	1.1–1.2	1.1	1.1–1.2
22.4–25.0	87,140	7,412	8.5	1.3	1.3–1.4	1.2	1.2–1.3
25.1–32.1	102,118	11,512	11.3	1.9	1.8–1.9	1.6	1.6–1.7
≥32.2	127,015	11,443	9.0	1.4	1.4–1.5	1.3	1.3–1.4
Women							
Mean annual temperature (°C§)							
<9.9	99,414	2,829	2.8	1.0		1.0	
9.9–11.1	159,423	4,905	3.1	1.1	1.0–1.1	1.1	1.0–1.1
11.2–13.4	133,356	4,287	3.2	1.1	1.1–1.2	1.1	1.0–1.1
13.4–17.2	132,516	5,138	3.9	1.4	1.3–1.5	1.3	1.3–1.4
≥17.3	141,275	5,048	3.6	1.3	1.2–1.4	1.3	1.2–1.3
Sunlight index							
<19.9	73,532	2,049	2.8	1.0		1.0	
19.9–22.3	167,815	4,983	3.0	1.1	1.0–1.1	1.1	1.0–1.1
22.4–25.0	115,202	3,866	3.4	1.2	1.1–1.3	1.2	1.1–1.2
25.1–32.1	139,928	5,913	4.2	1.6	1.5–1.7	1.6	1.5–1.6
≥32.2	169,507	5,396	3.2	1.2	1.1–1.2	1.1	1.1–1.2

* Crude odds ratios are adjusted for age (5-year levels) and race.
† CI, confidence interval.
‡ Odds ratios are adjusted for age (5-year levels), race, education, body mass index, hypertension, beverage consumption, and diuretic and vitamin C supplement use using logistic regression.
§ °F = 9/5 (°C) + 32.

transferred to warmer climates during summer but not winter months. Sunlight stimulates the increased production of 25-hydroxycholecalciferol in the skin, which, after conversion to 1,25 dihydroxy-vitamin D by the kidneys, enhances intestinal absorption of calcium. Elevated levels of circulating 1,25 dihydroxy-vitamin D have been found in patients with hypercalciuria (37) and excess urine calcium is linked to stone formation. The effect of sunlight on the regional odds of stones that we observed was not due to the latitude component of the sunlight index because adjustment for latitude did not have the same effect on regional variation in stones as did adjustment for sunlight (results not shown). The effect of sunlight was not as strong on the regional odds for women as men. This finding is interesting because sunlight exposure presumably influences the occurrence of calcium stones only and calcium stones are less common among women than among men (38). Perhaps some of the increased risk of calcium stones among men is due to higher levels of sunlight exposure, possibly related to occupational differences.

Some of the personal risk factors for stones that we studied did not appear to contribute to the geographic variability of kidney stones observed in this cohort. The regional variation in the odds of stones remained unchanged after adjusting singly or simultaneously for education level, hypertension, body mass, and diuretic and vitamin C supplement use.

CPS II participants who lived in the Southeast reported that they consumed more tea and colas and less alcohol than participants who resided elsewhere. Adjustment for beverage intake accounted for some but not all of the increased odds of stones in the Southeast relative to the Northwest. Among both men and women, differences in the consumption patterns of tea, coffee, non-diet cola drinks and alcohol appeared to contribute equally to the decrease in the regional odds

TABLE 3. Distribution of selected personal and environmental risk factors for kidney stones across geographic regions of residence among US men and women aged ≥30 years recruited for the Second Cancer Prevention Survey, 1982*

Risk factor and sex	Region†							
	Northwest	North Central	Midwest	Northeast	Southwest	South Central	Southeast	All regions
Temperature (mean °C‡)								
Men	10.5	10.1	9.3	11.3	15.8	18.2	18.4	12.9
Women	10.5	10.2	9.4	11.3	15.9	18.2	18.4	13.1
Sunlight index (mean value)								
Men	15.8	26.8	21.4	23.1	32.1	33.8	32.8	26.1
Women	15.8	27.0	21.5	23.2	32.2	33.8	32.8	26.2
Tea (mean servings/day)								
Men	1.6	2.0	1.8	1.9	1.7	2.5	2.5	2.0
Women	2.0	2.2	2.0	2.3	2.0	2.5	2.5	2.2
Cola (mean servings/day)								
Men	1.3	1.4	1.4	1.4	1.4	1.5	1.6	1.4
Women	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.3
Coffee (mean servings/day)								
Men	3.2	3.2	3.2	3.0	2.9	3.3	3.0	3.1
Women	3.0	3.0	3.0	2.8	2.7	3.0	3.0	2.8
Alcohol (mean servings/day)								
Men	2.3	2.2	2.3	2.3	2.4	2.2	2.0	2.3
Women	1.9	1.7	1.7	1.8	2.0	1.7	1.6	1.8

* Values are least-squares means adjusted for age (5-year groups) by analysis of covariance.
† States within regions are listed in the Appendix table.
‡ °F = 9/5 (°C) + 32.

of stones seen primarily in the Southeast region. Because the questionnaire did not ask about the intake of water, we were unable to examine total fluid intake for CPS II participants. It is possible that the high intake of tea and cola drinks that we observed in the Southeast compared with other regions might represent substitution of these lithogenic fluids for water, which appears to be protective (39, 40).

The consumption of alcohol has previously been linked to regional variations in the occurrence of kidney stones. In 1968, Mates et al. (6) reported that the occurrence rate of stones, as measured by hospitalizations, was lower in areas of Czechoslovakia where beer consumption was high. In the CPS II cohort, the prevalence of stones among men and women who lived in Utah was much higher than that among participants who resided in neighboring states (15). In fact, the state-specific prevalence of kidney stones in Utah was similar to that in Southeastern states. It may be that the common factor that links these widely separated areas is the reduced consumption of alcohol.

Several limitations of this study should be considered when interpreting these results. Because we measured risk factor exposures after stones had occurred, it is possible that we may have incorrectly specified the exposures of stone cases due to changes made as a consequence of having had a stone. However, many of the factors we examined were unlikely to have been influenced by the occurrence of stones, including age, race, education level, body weight, and hypertension. Similarly, because it seems improbable that people moved to a different state as a consequence of having stones, ambient temperature and sunlight exposures were unlikely to have changed differentially for participants with stones.

On the other hand, tea consumption may have been altered by an episode of stones. Prior to 1982, people who suffered from stones were commonly advised to avoid sources of oxalate such as tea (41). If people with stones limited tea consumption, then the positive association between tea and stones would be underestimated. Therefore, it is possible that variations in tea consumption contribute more to regional variation in stones than our analysis indicates.

The measures of ambient temperature and sunlight exposure that we used were crude and ecologic in nature. We recognize that, although residents of a state may have been presented with a similar potential for exposure, clearly not all individuals availed themselves equally of the opportunity. However, because we have no reason to suspect that people with stones differentially avoided sunlight or high temperatures, exposure misclassification was probably non-differential and may have led to underestimates of effect (42). Therefore, even though both indices were strongly associated with stones prevalence, and controlling for them modified regional associations with stones in ways that were consistent with their proposed biologic mechanisms, we consider our results to be preliminary.

TABLE 4. Relations between risk factors and regional prevalence of history of kidney stones among US men and women aged ≥30 years recruited for the Second Cancer Prevention Survey, 1982

Risk factors included in logistic regression models	Prevalence odds ratios for kidney stones by region*						
	Northwest†	North Central	Midwest	Northeast	Southwest	South Central	Southeast
Men							
Model 1. Age and race	1.0	1.1	1.1	1.2	1.2	1.4	1.9
Model 2. Age, race, education, body mass index, hypertension, and diuretic and vitamin C use	1.0	1.1	1.1	1.2	1.2	1.4	1.9
Model 2 and							
All beverages‡	1.0	1.0	1.1	1.1	1.2	1.2	1.6
Tea	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Cola	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Coffee	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Alcohol	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Mean temperature	1.0	1.0	1.1	1.1	1.1	1.2	1.5
Sunlight index	1.0	0.9	0.9	0.9	1.0	1.0	1.2
All risk factors	1.0	0.8	0.9	0.9	0.9	0.9	1.1
Women							
Model 1. Age and race	1.0	1.1	1.2	1.3	1.3	1.3	1.9
Model 2. Age, race, education, body mass index, hypertension, and diuretic and vitamin C use	1.0	1.1	1.2	1.3	1.3	1.3	1.9
Model 2 and							
All beverages‡	1.0	1.1	1.2	1.2	1.3	1.3	1.7
Tea	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Cola	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Coffee	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Alcohol	1.0	1.1	1.2	1.3	1.3	1.3	1.8
Mean temperature	1.0	1.1	1.2	1.2	1.2	1.2	1.7
Sunlight index	1.0	1.1	1.1	1.1	1.3	1.3	1.7
All risk factors	1.0	1.1	1.2	1.1	1.2	1.2	1.4

* States within regions are listed in the Appendix table.
† Indicates the reference region.
‡ All beverages includes milk, coffee, decaffeinated coffee, tea, diet and non-diet soft drinks, and alcohol.

We lacked information on other risk factors for stones. People who have had stones are more likely to have a first-degree relative with stones than those without such a history (43). Environmental exposures may be more likely to cause stone formation among people who are genetically susceptible. Perhaps some of the unexplained increased risk of stones in the Southeast is due to an enriched gene pool. Thun and Schober (44) found a high prevalence of stones among the relatives of both stone formers and controls in Tennessee. Defects in urine acidification can be inherited and are common in women with calcium stones (45).

In conclusion, we found that indices of ambient temperature and sunlight exposure were independently associated with the prevalence of kidney stones. Further, after adjustment for differences in temperature, sunlight, and the consumption of several beverages, the regional variation in the odds of stones was largely eliminated among men and substantially reduced in women.

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APPENDIX TABLE. Mean annual temperature and sunlight index by region and state of the United States (17, 18)

Region/state	Reporting cities	Temperature (°C (°F))*	Sunlight index†
Northwest			
Idaho	Boise	10.6 (51.1)	19.4
Oregon	Portland	11.7 (53.0)	16.0
Washington	Seattle, Spokane	9.6 (49.3)	14.6
North Central			
Kansas	Wichita	13.6 (56.4)	35.0
Montana	Great Falls	7.1 (44.7)	16.0
Nebraska	Omaha	10.6 (51.1)	22.7
North Dakota	Bismarck	5.2 (41.3)	16.5
South Dakota	Sioux Falls	7.4 (45.3)	19.4
Wyoming	Cheyenne	7.6 (45.7)	22.9
Midwest			
Illinois	Chicago, Peoria	9.9 (49.8)	21.6
Indiana	Indianapolis	11.2 (52.1)	22.7
Iowa	Des Moines	9.8 (49.7)	22.4
Kentucky	Louisville	13.4 (56.2)	25.1
Michigan	Detroit, Sault Ste. Marie	6.7 (44.2)	20.3
Minnesota	Duluth, Minneapolis	5.0 (41.0)	17.7
Missouri	Kansas City, St. Louis	12.6 (54.8)	25.4
Ohio	Cincinnati, Cleveland	10.8 (51.5)	22.1
Wisconsin	Milwaukee	7.8 (46.1)	19.9
Northeast			
Connecticut	Hartford	9.9 (49.8)	21.1
Delaware	Wilmington	12.2 (54.0)	21.1
Washington, DC	–	14.2 (57.5)	25.0
Maine	Portland	7.2 (45.0)	17.4
Maryland	Baltimore	12.8 (55.1)	25.0
Massachusetts	Boston	10.8 (51.5)	20.7
New Hampshire	Concord	7.4 (45.3)	21.0
New Jersey	Atlantic City	11.7 (53.1)	22.8
New York	Albany, Buffalo, New York City	9.8 (49.8)	22.3
Pennsylvania	Philadelphia, Pittsburgh	11.2 (52.3)	23.1
Rhode Island	Providence	10.2 (50.3)	21.8
Vermont	Burlington	6.7 (44.1)	17.2
Virginia	Norfolk, Richmond	14.8 (58.6)	28.0
West Virginia	Charleston	12.6 (54.8)	24.1
Southwest			
Arizona	Phoenix	21.8 (71.2)	35.5
California (North)	Sacramento, San Francisco	14.8 (58.6)	33.5
California (South)	Los Angeles, San Diego	17.3 (63.2)	33.5
Nevada	Reno	9.7 (49.4)	32.7
Utah	Salt Lake City	10.9 (51.7)	23.0
South Central			
Arkansas	Little Rock	16.6 (61.9)	28.8
Louisiana	New Orleans	20.1 (68.2)	34.9
New Mexico	Albuquerque	13.4 (56.2)	32.3
Oklahoma	Oklahoma City	15.5 (59.9)	29.7
Texas	Dallas, El Paso, Houston	18.8 (65.9)	35.1
Southeast			
Alabama	Mobile	19.7 (67.5)	31.1
Florida	Jacksonville, Miami	22.2 (72.0)	39.7
Georgia	Atlanta	16.2 (61.2)	29.8
Mississippi	Jackson	18.1 (64.6)	33.0
North Carolina	Charlotte, Raleigh	15.3 (59.5)	29.1
South Carolina	Columbia	17.4 (63.3)	30.3
Tennessee	Memphis, Nashville	15.8 (60.5)	28.4

* Mean annual temperature of the major weather reporting city in each state. If more than one city was listed, the average of the temperatures reported for those cities was used.

† Sunlight index for each state is a computed value based on ultraviolet radiation levels over a range of latitudes and annual cloud cover measurements.