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Original Contribution

Association of Summer Temperatures With Hospital Admissions for Renal Diseases in New York State: A Case-Crossover Study

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This study assessed the association between high temperatures and increased odds of hospitalization for renal diseases that, to date, has been examined in only a small number of studies. A case-crossover design was used to study 147,885 hospital admissions with renal diagnoses during July and August, 1991–2004, in New York State. Regional temperature, humidity, and barometric pressure data from automated monitors were used as exposure indicators. By use of time-stratified referent selection and conditional logistic regression analysis, an overall 9% increase in odds of hospitalization for acute renal failure per 5°F (2.78°C) was found for mean temperature at a 1-day lag (odds ratio = 1.09, 95% confidence interval: 1.07, 1.12). The results suggest increased susceptibility to hospitalization for acute renal failure for blacks, Hispanics, people aged 25–44 years, and those in the lowest income quartile. The odds varied geographically with the largest associations found in the more urban regions. Increased odds of hospitalization were also found for urinary tract infections, renal calculi, lower urinary calculi, and other lower urinary tract disorders. The findings can help to identify vulnerable subpopulations and to inform decisions and policies regarding adaptation strategies and heat-warning systems.

case-crossover; climate change; effect modifiers (epidemiology); heat; morbidity; New York State; renal disease; vulnerable populations

Abbreviations: CI, confidence interval; OR, odds ratio.

It is well established that extremely high temperatures contribute to increases in mortality (1). More recent studies have found that high ambient temperatures are associated with increases in hospitalizations for not only heat-related conditions, such as heat stroke (2, 3), but also other conditions, such as respiratory (4, 5) and cardiovascular (4–9) disorders. Renal and urinary disorders, on the other hand, have not received as much attention, in spite of the fact that the kidney and urinary system both affect and are affected by the body's fluid balance, which can be compromised by exposure to high temperatures. Some studies have documented the relation between high ambient temperature and the development of calculi (10–12), and acute renal failure can be a consequence of heat stroke (13–16).

The majority of studies of the association of high temperature and renal disorders have focused on hospital admissions or emergency department visits during heat waves (16–21). Three studies found increases in hospital admissions for acute renal failure: 388% in Chicago (21), 26% in Adelaide, South Australia (12), and 11% in California (18). The only study to examine exposure to typical summer temperatures found that the risk of hospitalization for acute renal failure increased 7.4% per 10°F (5.56°C) (22). Only 2 studies explored the interaction with demographic variables (17, 22). No previous work has examined the interaction of income and temperature, and there has been only limited exploration of non-acute renal failure conditions.

Our primary objective was to evaluate the association between summer temperatures and hospital admissions for acute renal failure and other renal disorders in New York State by examining several temperature indicators including mean, maximum, and minimum temperature, as well as apparent temperature at various exposure intervals, to determine which show the largest associations with hospitalization. A secondary objective was to evaluate whether the temperature-hospitalization relation is modified by geographic location or by demographic variables, such as age, sex, race, ethnicity, or income.

MATERIALS AND METHODS

Study population and health outcomes

The study population included all residents of New York State. Hospital discharge data in New York State from 1991 to 2004 for renal diseases were obtained from the New York State Department of Health's Statewide Planning and Research Cooperative System (SPARCS) (23), a legislatively mandated database that contains hospital discharge data for at least 95% of all acute-care hospital admissions in New York State, excluding admissions to psychiatric and federal hospitals. To define cases, we used the principal diagnosis field that indicates the primary medical condition that was treated during the hospitalization. Admissions were included that had a principal diagnostic code for a disease of the kidneys or urinary system, specifically the *International Classification of Diseases,* Ninth Revision (ICD-9), codes 580–599 and 788. Eight diagnostic categories were created along clinical, anatomic, or physiologic lines, resulting in the following categories: acute renal failure (code 584), chronic kidney disease (code 585), urinary tract infections (code 599), renal calculi (code 592), lower urinary tract calculi (code 594), nephritis and nephrosis (codes 580–583, 590, 591), other kidney and ureter disorders (codes 586–589, 593), and other lower urinary tract disorders (codes 595–598, 788). Acute renal failure was the diagnosis of main interest because of its acute nature and the fact that its physiologic susceptibility to heat is most clearly understood (24). In addition to discharge diagnoses, the data included hospital admission date, age, gender, race, ethnicity, and residential address. Ethnicity values are Hispanic and non-Hispanic. Race values are white, black, Native American, Asian, Hawaiian/Pacific Islander, and other. Data from the 1990 and 2000 US Census at the census block level were used to derive an indicator of socioeconomic status.

Weather data and exposure assignment

Hourly observations of temperature, dew point, wind speed, and atmospheric pressure from National Weather Service stations in New York State were obtained from the Data Support Section of the Computational and Information Systems Laboratory at the National Center for Atmospheric Research. These were used to derive daily means, minimums, and maximums for each variable. In addition, Steadman's universal apparent temperature (25) was calculated by using the following formula that takes into account humidity and wind speed: universal apparent temperature $= -2.7 + 1.04 \times$ temperature $+ 2.0 \times$ vapor pressure $- 0.65 \times$ wind speed, where temperature is in degrees Celsius, vapor pressure is in kilopascals, and wind speed is in meters per second. Mean, minimum, and maximum universal apparent temperature values were calculated.

Exposure data were linked with cases by geocoding each case and assigning it to 1 of the 14 weather regions that have been delineated in New York State (Figure 1). These regions were based on the National Climatic Data Center's 10 New York State climate divisions (26). Because there is often a need to address the influence of ozone when studying hospital admissions related to other diseases such as respiratory or cardiovascular disease, the climate divisions were modified by overlaying and merging them with the 11 ozone regions developed for the state by Chinery and Walker (27). This resulted in 14 regions of relatively homogeneous weather and ozone exposures. Although we found no previous studies documenting a relation between pollution and renal disorders and there is no plausible biologic mechanism for such a relation, we have retained the use of our temperature-ozone regions to maintain comparability with our studies of hospital admissions for other diagnoses.

Each hospital admission was geocoded at the street level with Map Marker Plus (MapInfo Corp., Troy, New York). Ninety-five percent of the addresses were geocoded automatically, 4% were geocoded interactively, and less than 1% could not be geocoded. The map of geocoded addresses was overlaid onto the map of the weather regions by use of MapInfo (MapInfo Corp.). Because weather data were not available for Staten Island, admissions for residents of Staten Island were combined with those of Region 1 (New York City-LaGuardia Airport).

Study design and statistical analysis

We used a case-crossover design, an appropriate method to use with case-only data, particularly when the outcome is acute and the exposure is brief and transient (28). Because it is important that there is stationarity within the referent window (29), the study period was restricted to the months of July and August, as the adjacent months showed increasing or decreasing temperature trends. A time-stratified approach was used for referent selection, with each month serving as a referent window for the cases within the month. Referent dates were all dates at 1, 2, or 3 weeks before and/or after the index (case) date.

The data were analyzed with conditional logistic regression by use of the PHREG procedure in SAS, version 9.2, statistical software (SAS Institute, Inc., Cary, North Carolina). State-wide analyses of acute renal failure were conducted with each of the available exposure variables: daily maximum and minimum values of actual and apparent temperatures, lagged by up to 5 days before admission. The exposure indicator with the best model fit was determined and used in the subsequent analyses to evaluate interactions between temperature and demographic variables on the multiplicative scale. Model fit was assessed by examining the significance of the type III Wald chi-square test for the interaction terms.

The same analyses were then repeated for each of the 8 diagnostic groups. All conditional logistic regression models were adjusted for relative humidity and barometric pressure, except those using universal apparent temperature that already incorporates humidity. Observations that had missing data for covariates (0.2%–12%) involved in the interaction analyses were excluded separately for each stratifying covariate and noted in the tables.

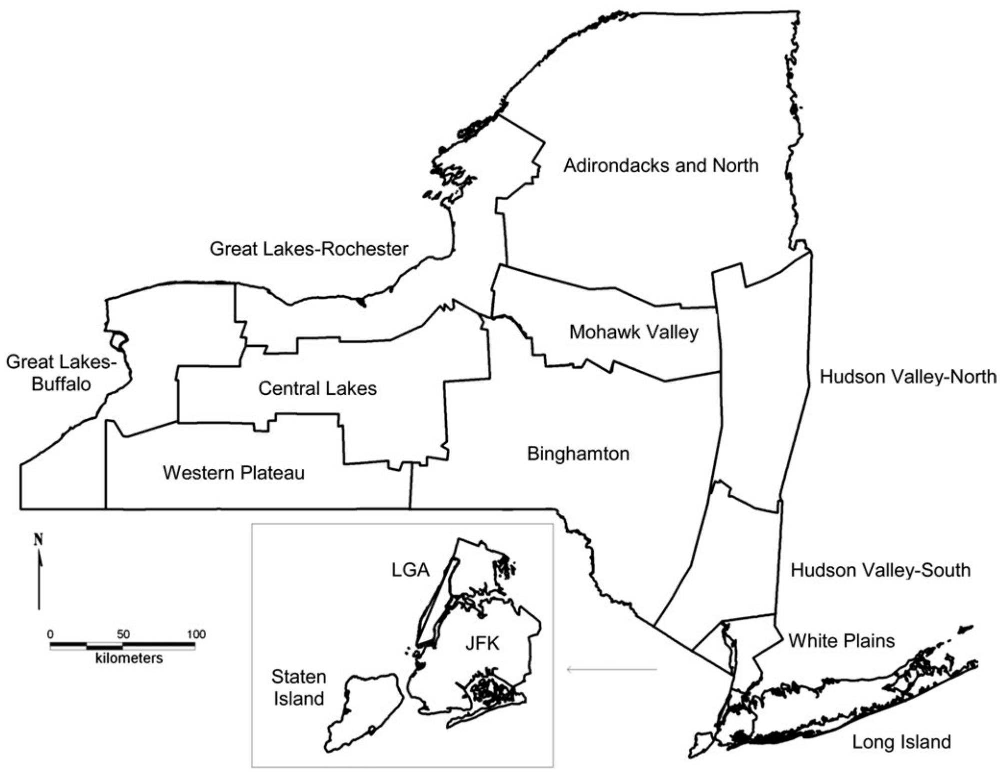

Figure 1. Map of New York State showing 14 weather regions based on climate divisions and ozone regions. JFK, John F. Kennedy International Airport; LGA, LaGuardia Airport; N, north.

RESULTS

There were 147,885 hospital admissions with principal diagnoses of renal diseases during the months of July and August in the years 1991–2004. Using the time-stratified method of referent selection, 486,518 referent dates were created (after removing dates with missing weather data). The number of referent dates per case ranged from 1 to 4, with 68% of cases having 3 referent dates and 25% of cases having 4 referent dates.

Population and regional characteristics

Table 1 presents an overview of descriptive weather and demographic data by weather region. Temperatures vary considerably by region. The ranges for mean, minimum, and maximum temperatures are 9.2°F (5.1°C), 13.1°F (7.3°C), and 7.4°F (4.1°C), respectively, with the highest temperatures generally occurring in the southern part of the state.

The study population also varies demographically by region. The proportion of the population that is white ranges from 45.3% in the New York City area (Region 1) to 97.3% in the Adirondack area (Region 8). Similarly, the proportions of blacks and Hispanics show wide ranges across the state, while age and sex distributions vary much less among regions. The median income is noticeably higher in the downstate regions, with the exception of the New York City-LaGuardia Airport area (Region 1), where it is comparable to those of the upstate regions.

Table 2 shows wide regional variation in numbers of hospitalizations due, in part, to the regional variations in population (data not shown). To facilitate comparisons among regions, the rates per 10,000 of population for all renal admissions per month during the study period are provided in Table 2. The monthly rates range from a low of 2.1/10,000 in the Hudson Valley South area (Region 6) to the highest rate of 3.1/10,000 in the Western Plateau area (Region 13).

Association of temperature with acute renal failure and interactions with demographic variables

The first set of analyses examined admissions due to acute renal failure. Table 3 shows the results of the conditional logistic regressions of the 6 temperature indicators (mean, minimum, and maximum actual temperatures and mean, minimum, and maximum universal apparent temperatures) with the odds ratios for the association of temperature and hospitalization for acute renal failure. The exposures were the temperatures on the day of hospitalization (lag 0) and on each of the previous 5 days (lags 1–5). Across all temperature indicators, lags 0–2 showed significant increases in the odds of hospitalization and, while the point estimates were fairly close, the mean actual temperature indicator had the largest estimate at each lag. The magnitude of the association between mean actual temperature and hospital admissions increased slightly from lag 0 to a maximum at lag 1, decreased slightly at lag 2, and became null at lags 3–5.

Table 1. Regional Daily Temperature and Demographic Characteristics of Hospital Admissions for Renal Diagnoses in New York State, July–August, 1991–2004

Region	Daily Temperature for July and August (°F)[a]			Demographic Characteristics					
	Mean	Minimum	Maximum	Mean Age (SD), years	Median Income (USD)	Race/Ethnicity, %			% Female
						White	Black	Hispanic	
1 (New York City-LaGuardia Airport)[b]	76.9	70.8	83.8	53.8 (26.4)	37,262	45.3	21.8	20.3	56.0
2 (New York City-John F. Kennedy International Airport)	74.8	68.6	81.8	56.7 (25.4)	39,521	56.5	24.0	8.5	52.6
4 (Long Island)	73.5	66.4	81.1	56.2 (24.6)	67,963	81.0	8.1	6.3	50.2
5 (Westchester)	72.5	64.5	81.2	57.1 (23.8)	64,489	72.9	11.8	10.3	49.3
6 (Hudson Valley-South)	72.2	62.3	82.5	56.2 (23.6)	53,857	83.1	4.9	1.9	49.1
7 (Hudson Valley-North)	69.9	60.0	80.0	57.7 (24.9)	43,044	77.8	4.4	1.3	56.7
8 (Adirondacks and North)	68.7	58.7	78.8	56.1 (23.6)	33,803	97.3	0.9	0.4	51.5
9 (Mohawk Valley)	69.0	59.9	78.8	57.4 (24.3)	34,216	94.1	2.7	1.2	54.2
10 (Binghamton)	67.7	59.7	76.4	57.0 (24.4)	37,348	90.4	2.0	1.8	52.3
11 (Rochester)	69.0	59.6	78.3	55.7 (24.6)	42,407	85.7	9.4	2.9	54.7
12 (Central Lakes)	70.7	61.5	80.1	57.5 (24.8)	39,710	87.4	5.2	0.5	54.4
13 (Western Plateau)	68.8	57.7	80.6	56.6 (24.0)	34,528	95.1	1.0	0.1	54.8
14 (Buffalo)	70.5	61.9	79.0	58.6 (24.3)	38,518	82.5	8.9	1.3	55.1
Statewide	71.1	62.4	80.2	55.9 (25.2)	44,900	67.2	13.9	10.0	53.7

Abbreviations: SD, standard deviation; USD, US dollars.
[a] To convert values given in degrees Fahrenheit (°F) to degrees Celsius (°C): (°F – 32) × 0.556 = °C.
[b] Includes Staten Island.

Because this was found to be a consistent pattern with few exceptions, only the lag 1 mean actual temperature results are reported for the interaction models.

The results of the interaction analyses with mean temperature at lag 1 are shown in Table 4. Effect modification was found for race and ethnicity as shown by the significant Wald tests for interaction terms. Compared with that for whites (odds ratio (OR) = 1.08, 95% confidence interval (CI): 1.05, 1.11), the odds ratio for Asians (OR = 0.88, 95% CI: 0.74, 1.05) was significantly lower ($P = 0.03$), while the odds ratio for blacks (OR = 1.14, 95% CI: 1.08, 1.20) was marginally higher ($P = 0.06$). Hispanics had a 20% increase in odds per 5°F (2.78°C), which was significantly greater than that of non-Hispanics (9%). Marginally elevated odds ratios (compared with their respective referents) were also observed for those 25–44 years of age (OR = 1.18, 95% CI: 1.08, 1.27) and for those in the lowest quartile of income (OR = 1.13, 95% CI: 1.08, 1.18), but the overall Wald tests for homogeneity were not statistically significant. It should be noted that the estimates for the 2 youngest age groups and the Native American and Asian groups are imprecise because of small samples sizes ($n = 38$, 179, 23, and 194, respectively).

Regional acute renal failure effects

As shown by the Wald test in Table 4, there was no statistically significant effect modification by region. Five of the 13 regions showed significantly increased odds of hospitalization for acute renal failure associated with mean temperature at lag 1: New York City-LaGuardia Airport (including Staten Island), New York City-John F. Kennedy International Airport, Long Island, Rochester, and Buffalo. The highest effects were in the New York City-John F. Kennedy International Airport area (OR = 1.14, 95% CI: 1.05, 1.23), Rochester area (OR = 1.12, 95% CI: 1.03, 1.22), and Buffalo area (OR = 1.11, 95% CI: 1.03, 1.19).

Other renal diagnoses

The patterns of effects for the other renal categories vary widely (Figure 2). For acute renal failure (Figure 2A), the largest association between mean temperature and admissions occurs at lag 1 (OR = 1.09, 95% CI: 1.07, 1.12), but significant associations occurred at lags 0 and 2 as well (OR = 1.06, 95% CI: 1.04, 1.09 and OR = 1.06, 95% CI: 1.03, 1.08, respectively). The effects on admissions for urinary tract infections were strongly linear, with the largest effect (OR = 1.07, 95% CI: 1.06, 1.08) occurring at lag 0 and linearly decreasing effects to lag 4. Renal calculi admissions (Figure 2B) were significantly associated with mean temperature at all lags, with the trend increasing to lag 3 (OR = 1.06, 95% CI: 1.05, 1.08) and decreasing after that. Temperature appeared to affect chronic kidney disease (Figure 2A) at lags 0 and 4, but the estimates were not statistically significant. Although most significant effects occurred on the earlier lag days, the effects on lower urinary tract disorders occurred at lags 2–5.

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Table 2. Counts of Hospital Admissions for Renal Diagnoses by Weather Region and Diagnostic Subcategory in New York State, July–August, 1991–2004

Region	Hospital Admissions During July and August, 1991–2004									
	Acute Renal Failure, no.	Chronic Kidney Disease, no.	Urinary Tract Infection, no.	Nephritis and Nephrosis, no.	Renal Calculi, no.	Lower Urinary Calculi, no.	Lower Urinary Tract Disorders, no.	Other Kidney Disorders, no.	Total Renal, no.	All Renal/10,000 Population/Month
1 (New York City-LaGuardia Airport)[a]	4,100	1,965	20,024	8,279	9,580	831	4,664	2,038	51,481	3.0
2 (New York City-John F. Kennedy International Airport)	1,170	561	6,179	1,919	3,095	332	1,623	626	15,505	3.0
4 (Long Island)	1,996	739	7,280	2,949	5,864	364	2,368	962	22,522	2.9
5 (Westchester)	735	292	2,730	1,110	2,702	137	1,131	480	9,317	2.7
6 (Hudson Valley-South)	382	111	1,392	538	1,382	56	501	265	4,627	2.1
7 (Hudson Valle-North)	487	158	2,132	924	1,411	69	478	306	5,965	2.2
8 (Adirondacks and North)	222	71	880	463	802	35	335	117	2,925	2.9
9 (Mohawk Valley)	243	54	1,050	477	891	31	278	155	3,179	2.8
10 (Binghamton)	456	133	1,850	819	1,482	69	570	301	5,680	2.6
11 (Rochester)	691	163	2,360	1,247	1,863	78	452	277	7,131	2.4
12 (Central Lakes)	492	142	2,006	894	1,279	72	462	281	5,628	2.2
13 (Western Plateau)	212	78	888	381	863	34	233	139	2,828	3.1
14 (Buffalo)	1,184	269	3,972	1,287	2,873	97	852	563	11,097	2.8
Statewide	12,370	4,736	52,743	21,287	34,087	2,205	13,947	6,510	147,885	2.8

[a] Includes Staten Island.

Table 3. Odds Ratios for the Associations Between a 5°F (2.78°C) Change in Lagged Mean, Minimum, and Maximum Temperature (Actual and Apparent) and Hospital Admissions for Acute Renal Failure in New York State, July–August, 1991–2004

Lag, days	Actual Temperature[a]						Apparent Temperature[b]					
	Mean		Minimum		Maximum		Mean		Minimum		Maximum	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
0	1.064	1.040, 1.089	1.062	1.039, 1.085	1.043	1.024, 1.063	1.044	1.025, 1.063	1.035	1.018, 1.053	1.035	1.020, 1.053
1	1.090	1.065, 1.116	1.082	1.059, 1.105	1.065	1.045, 1.086	1.060	1.041, 1.080	1.051	1.033, 1.068	1.048	1.032, 1.066
2	1.059	1.034, 1.083	1.045	1.023, 1.068	1.042	1.023, 1.062	1.042	1.023, 1.062	1.035	1.018, 1.052	1.035	1.018, 1.052
3	1.018	0.995, 1.042	1.018	0.996, 1.039	1.011	0.992, 1.030	1.012	0.993, 1.031	1.012	0.996, 1.029	1.006	0.990, 1.022
4	1.006	0.984, 1.030	1.008	0.986, 1.029	1.005	0.986, 1.024	0.995	0.977, 1.013	0.996	0.980, 1.013	0.995	0.979, 1.012
5	1.016	0.993, 1.040	1.009	0.988, 1.030	1.016	0.997, 1.035	1.005	0.987, 1.012	1.000	0.984, 1.017	1.008	0.992, 1.025

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Actual temperature is adjusted for relative humidity and barometric pressure.
[b] Apparent temperature is adjusted for barometric pressure only.

Other findings

To assess the potential influence of extremely high temperatures on the overall association between mean temperature and acute renal failure admissions, we ran a sensitivity analysis excluding observations having a mean temperature greater than the 90th percentile of the seasonal norm. The results did not differ from those of the original analysis (results not shown).

Humidity and barometric pressure were associated with less than 1% change in the odds of admissions in most models. However, model fit statistics indicated that their inclusion in the models produced a slight but significant improvement in the model fit, and they were therefore retained.

DISCUSSION

In our study of the relation of summer temperatures to hospital admissions for acute renal failure and other renal diagnoses, we found that mean actual temperature is a stronger exposure indicator than either minimum or maximum actual temperature or universal apparent temperature. Most studies to date have focused on 1 indicator, often apparent temperature, without explicitly examining the sensitivity of each indicator. A recent exploration of the best temperature predictor of mortality has concluded that there is no one best predictor (30). It could be that the strength of the temperature indicator varies with the health outcome, the climatic conditions, and the geographic location and that the choice of indicator needs to take these factors into account.

Our overall results are similar to those of other studies in which acute renal failure was found to be associated with high ambient temperatures. Although most of the previous studies considered only heat waves (16–21), our study was one of only a few to examine the influence of all summer temperatures on renal admissions. Our findings differ in several respects from those of the study by Green et al. (22) in which summer temperatures in California were found to be associated with increased hospital admissions for acute renal failure. Although we found larger estimates at lag 1, the California study found the largest association at lag 0. In addition, the size of the estimate in the present study (9.0% per 5°F (2.78°C)) is about twice that of the California study (7.4% increase per 10°F (5.56°C)). Both of these differences could be attributed to a difference in acclimatization in the 2 study areas. Summers in California are generally hotter than those in New York, perhaps making New Yorkers less acclimatized and more vulnerable to smaller increases in temperature. On the other hand, the shorter lag between exposure and hospitalization in California could be due to the relatively higher temperatures involved.

The biologic mechanism underlying the relation of heat and renal disease is unclear. Previous studies have documented increased incidence of renal calculi associated with exposure to hot conditions, presumably the result of disrupted fluid balance (10–12). Other studies have found renal failure to occur as a consequence of heatstroke due to either dehydration or direct kidney damage from rhabdomyolysis (13–16).

It could be hypothesized that the association between mean temperature and acute renal failure hospitalization is being driven by temperatures in the upper ranges. We addressed this question by omitting the observations having temperatures above the 90th percentile for the study period and found that the result remained the same. This is a finding not previously reported in the literature that suggests that the odds for acute renal failure increase smoothly with temperature in summer up to and including the 90th percentile. Unfortunately, we did not have sufficient power to assess whether the odds are the same above the 90th percentile.

Although Green et al. (22) reported that race and ethnicity had no effect on the results in their study, we found that blacks and Hispanics had approximately twice the odds of whites and non-Hispanics, respectively, for temperature-related hospitalizations for acute renal failure. The reason for the discrepancy between the studies is not clear. A reason for the higher susceptibility of blacks could be related to their lower air conditioner use relative to that of whites, a finding documented in a multicity study of air conditioner prevalence (31). The estimate that we found in the group aged 25–44 years (OR = 1.18, 95% CI: 1.08, 1.27) was twice that of the referent group aged 45–64 years but not significantly different (Wald chi-square, $P = 0.09$). No other studies report an age differential such as this, although Hansen et al.

Table 4. Lag 1 Association Between a 5°F (2.78°C) Change in Mean Temperature and Hospitalizations for Acute Renal Failure in New York State, July–August, 1991–2004, Stratified by Demographics and Geographic Region and Adjusted for Relative Humidity and Barometric Pressure

Demographic Variables[a] and Subgroups	No. of Cases	OR	95% CI	Wald Test P Value[b]
Gender				0.44
Female	5,976	1.10	1.07, 1.14	0.44
Male	6,394	1.08	1.05, 1.12	Referent
Age, years				0.28
4 or younger	38	0.91	0.60, 1.37	0.39
5–24	179	0.96	0.81, 1.15	0.21
25–44	879	1.18	1.08, 1.27	0.09
45–64	2,455	1.09	1.03, 1.14	Referent
65–84	6,485	1.08	1.05, 1.12	0.99
85 or older	2,334	1.10	1.04, 1.15	0.76
Race				0.03
White	8,485	1.08	1.05, 1.11	Referent
Black	2,228	1.14	1.08, 1.20	0.06
Native American	23	1.07	0.68, 1.69	0.98
Asian	194	0.88	0.74, 1.05	0.03
Ethnicity				0.05
Hispanic	717	1.20	1.09, 1.32	0.05
Non-Hispanic	10,350	1.09	1.06, 1.12	Referent
Income quartiles, USD				0.17
≤31,406	3,153	1.13	1.08, 1.18	0.07
31,407–40,836	2,909	1.10	1.06, 1.15	0.29
40,837–55,869	3,110	1.06	1.02, 1.11	0.91
>55,869	3,168	1.07	1.02, 1.12	Referent
Region				0.70
1 (New York City-LaGuardia Airport and Staten Island)	4,100	1.11	1.07, 1.15	0.89
2 (New York City-John F. Kennedy International Airport)	1,170	1.14	1.05, 1.23	0.58
4 (Long Island)	1,996	1.06	1.00, 1.13	0.42
5 (Westchester)	735	1.06	0.98, 1.16	0.50
6 (Hudson Valley-South)	382	1.11	0.98, 1.25	0.95
7 (Hudson Valley-North)	487	1.03	0.93, 1.15	0.32
8 (Adirondacks and North)	222	0.99	0.86, 1.14	0.18
9 (Mohawk Valley)	243	1.12	0.96, 1.30	0.91
10 (Binghamton)	456	1.02	0.91, 1.14	0.22
11 (Rochester)	691	1.12	1.03, 1.22	0.81
12(Central Lakes)	492	1.05	0.95, 1.16	0.42
13 (Western Plateau)	212	1.14	0.97, 1.35	0.71
14 (Buffalo)	1,184	1.11	1.03, 1.19	Referent

Abbreviations: CI, confidence interval; OR, odds ratio; USD, US dollars.

[a] Deleted cases because of missing data for race ($n = 1,440$, 11.6%); ethnicity ($n = 1,303$, 10.5%); and income ($n = 30$, 0.2%).

[b] Wald chi-square tests for homogeneity; the values for demographic variables indicate the statistical significance of the overall interaction term; subgroup values indicate comparison with the referent.

(17) found significant results for all renal disease for the group aged 15–64 years, which includes our group aged 25–44 years. On the other hand, Green et al. (22) found no association between temperature and acute renal failure admissions for people aged 19–64 years. The reason for the elevated odds among those 25–44 years of age is unclear but could be due to this age group's engaging in higher levels of outdoor activity in hot conditions, either occupationally or recreationally. Although the median household income varies among weather regions, it did not significantly modify the relation between temperature and hospitalization in stratified analyses. The estimate in the lowest income quartile, however, was marginally lower than that in the highest income quartile (Wald chi-square, $P = 0.07$), suggesting higher risk among the economically disadvantaged. No studies of the temperature-morbidity relation have previously addressed this issue. However, it is consistent with 2 studies of temperature-associated mortality cited by Basu and Samet (1) in their extensive review. Because our income indicator was a relatively crude measure derived from census block data, further work using a more sensitive indicator is needed.

There is no obvious explanation for the geographic variation of the relation between temperature and hospitalization for renal disease. Significant associations were found in New York City and Long Island, as well as in the 2 upstate regions of Buffalo and Rochester. As these are the more urban regions of the state, it is possible that the influence of temperature was magnified by the urban heat island effect (32). Some of the nonsignificant results may be due to lack of power since some of the weather regions have very small numbers of cases. However, one of the largest estimates (OR = 1.13, 95% CI: 1.03, 1.24) was found in the Rochester region, where there were only 691 acute renal failure cases, while the Westchester region had a nonsignificant result with 735 cases, suggesting that power issues may not account for all of the geographic differences in estimates.

Other renal diseases including urinary tract infections, renal calculi, lower urinary calculi, and lower urinary tract infections were found to be associated with mean temperature. The fact that both upper and lower calculi groups each showed increased odds at several lags is biologically consistent with a relation between dehydration and the formation of calculi. No studies of other renal diagnoses were found for comparison.

This study is one of the few to examine the association between ambient temperature and hospital admissions for renal disease, and it is 1 of only 2 that examine summer temperatures below the level of a heat wave. In addition, we have attempted to identify the characteristics of those most vulnerable by analyzing the modifying effects of multiple demographic indicators including sex, age, race, ethnicity, income, and geographic location. By using a case-crossover design, we have eliminated interindividual variation, a major source of uncontrolled confounding in epidemiologic studies (33). Additional strengths include examination of lagged exposures and comparison of various temperature indicators, as well as determining that the temperature-admission association we found was not driven primarily by the upper temperature range.

A limitation of our study is its reliance on ecologic-level exposure data. Exposure temperature was assigned on the

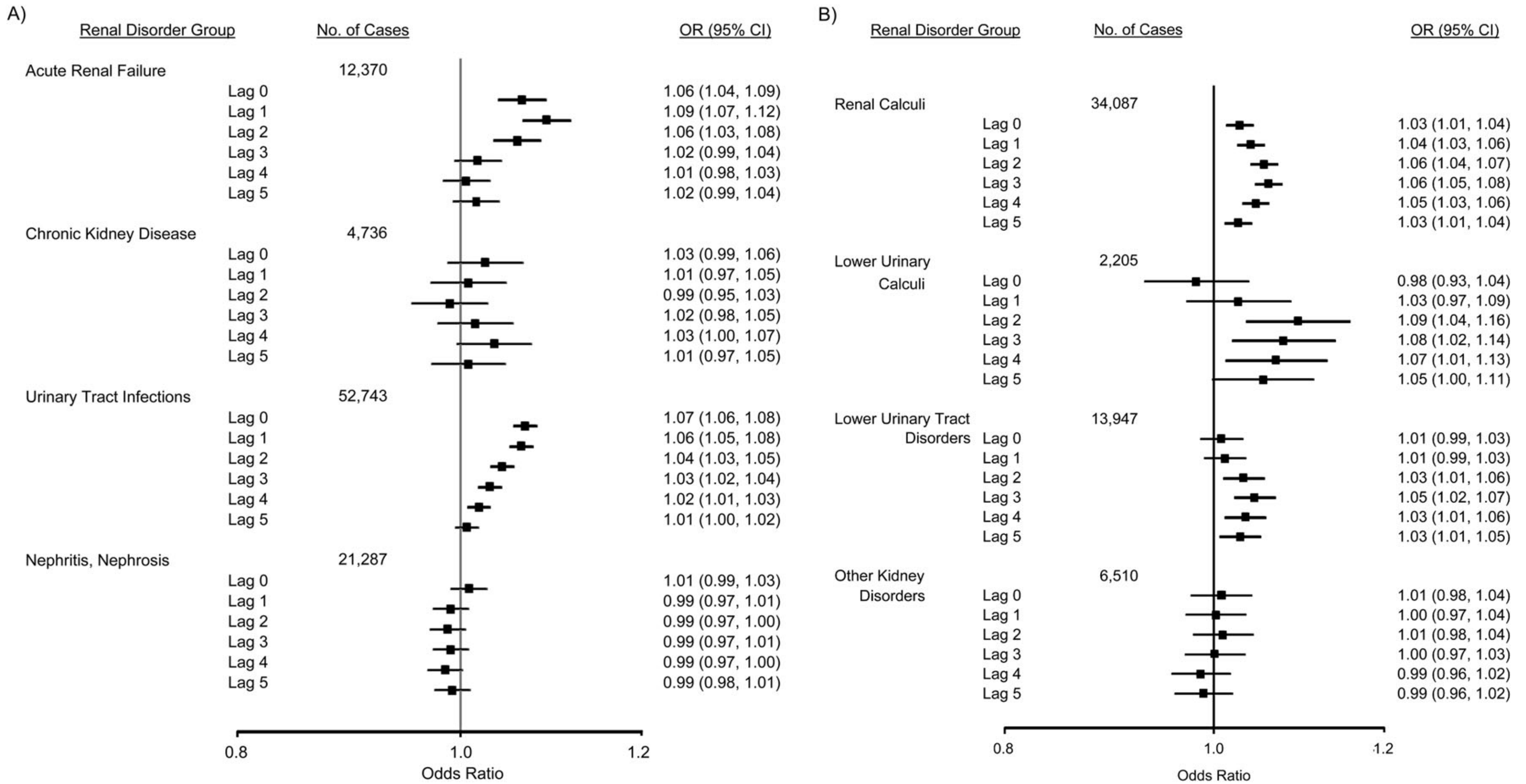

Figure 2. In A and B, associations are shown between a 5°F (2.78°C) change in lagged mean temperature and hospital admissions for 8 renal diagnostic categories in New York State, July–August, 1991–2004. All models were adjusted for relative humidity and barometric pressure. Scale is logarithmic. CI, confidence interval; OR, odds ratio.

basis of residential address and took no account of personal activity. Similarly, we do not know which individuals had access to air conditioning or other mitigation resources, another source of exposure misclassification. On the outcome side, use of hospitalization data ensures that we have captured the most serious of illnesses (e.g., acute renal failure), but there may be an association between temperature and emergency department or physician visits for less severe symptoms. A further limitation is that small cell sizes prevented us from examining demographic effect modification within regions. These limitations are common in studies of this type.

Our findings add to the growing body of work that documents the association of high temperature and morbidity, particularly hospital admissions for renal diagnoses. We found that the largest result for the temperature-acute renal failure hospitalization relation occurred at a 1-day lag in mean temperature and that the association is modified by certain demographic variables. Our findings suggest that blacks and Hispanics are more vulnerable to heat with regard to this outcome. We also found a surprising increase in the odds of hospitalizations for acute renal failure hospitalizations among people aged 25–44 years. These findings can be useful in developing adaptation strategies and heat-warning policies.

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