Warmer weather as a risk factor for hospitalisations due to urinary tract infections

J. E. Simmering[1], J. E. Cavanaugh[2], L. A. Polgreen[3] and P. M. Polgreen[4]

[1]Signal Center for Health Innovation, The University of Iowa Health Ventures', Coralville, Iowa, USA; [2]Department of Biostatistics, The University of Iowa, Iowa City, Iowa, USA; [3]Department of Pharmacy Practice and Science, The University of Iowa, Iowa City, Iowa, USA and [4]Departments of Internal Medicine and Epidemiology, The University of Iowa, Iowa City, Iowa, USA

Original Paper

Abstract

The incidence of urinary tract infections (UTIs) is seasonal, and this seasonality may be explained by changes in weather, specifically, temperature. Using data from the Nationwide Inpatient Sample, we identified the geographic location for 581 813 hospital admissions with the primary diagnosis of a UTI and 56 630 773 non-UTI hospitalisations in the United States. Next, we used data from the National Climatic Data Center to estimate the monthly average temperature for each location. Using a case–control design, we modelled the odds of a hospital admission having a primary diagnosis of UTI as a function of demographics, payer, location, patient severity, admission month, year and the average temperature for the admission month. We found, after controlling for patient factors and month of admission, the odds of a UTI diagnosis increased with higher temperatures in a dose-dependent manner. For example, relative to months with average temperatures of 5–7.5 °C, an admission in a month with an average temperature of 27.5–30 °C has 20% higher odds of a primary diagnosis of UTI. However, in months with extremely high average temperatures (above 30 °C), the odds of a UTI admissions decrease, perhaps due to changes in behaviour. Thus, at a population level, UTI-related hospitalisations are associated with warmer weather.

Introduction

Urinary tract infections (UTIs) are common [1]. Although most UTIs are treated on an out-patient basis, severe or complicated cases often require hospitalisation [2]. Over the past decade, the incidence of hospitalisations for UTIs has increased [3, 4], perhaps in part due to increasing resistance to antimicrobials used to treat out-patient UTIs [2, 3, 5], and the resulting need to admit patients to the hospital for treatment with intravenous antimicrobials [4]. Individual-level-risk factors for UTIs include female sex [6], previous history of UTIs [7], sexual activity [8] and perhaps limited fluid intake or dehydration [9–12].

In addition to individual-level-risk factors, environmental risk factors for UTIs may also exist. Indeed, single-centre studies have demonstrated a seasonal increase in UTIs, with more cases occurring in summer months [13–15]. Also, Internet search terms related to UTIs peak in summer months in several parts of the world, indicating a strong seasonal interest in UTIs in the Internet-using public [16]. In the USA, the incidence of admissions is highly seasonal for patients admitted to the hospital with a primary diagnosis of UTI and for admissions with a primary diagnosis of pyelonephritis [4]. The reasons for the observed seasonality in the incidence of UTIs are unknown [14]. Possible explanations for the seasonality include 'inadvertent prophylaxis' with antimicrobials to treat respiratory infections in the winter [14], and changes in sexual partners and travel [17]. Another hypothesis is that weather, specifically warmer temperatures in the summer [18, 19], lead to the observed summer spike. Temperature may have an impact on hosts, urinary pathogens or both. From the standpoint of the host, UTIs may be more common in the warm summer months if higher temperatures reduce hydration levels, even sub-clinically, resulting in lower levels of urine production and decreased the clearance of potential urinary pathogens [10–12]. In addition, if the temperature is the driving factor in the seasonality, this may explain why seasonality was not observed in studies in countries with cooler climates. For instance, studies in Sweden, Norway, the Netherlands and the UK do not demonstrate a seasonal incidence of UTIs [20–26].

The purpose of this paper is to determine if and to what extent the seasonality of UTIs may be attributable to changes in temperature, specifically higher temperatures. We explored this question using a case–control design and historical weather data from the National Oceanic and Atmospheric Administration in conjunction with a nationally representative sample of hospital admissions in the continental USA from 1998 to 2011 to ensure a geographically and climatologically diverse sample.

CAMBRIDGE UNIVERSITY PRESS

Methods

Data sources and case definition

Data for inpatient admissions were obtained through the Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS), maintained by the Agency for Healthcare Research and Quality (AHRQ). The NIS is based on a stratified sample of hospitals, with information on 20% of all discharges in the USA in a given year. Observational studies using de-identified data such as these are deemed exempt by our Institutional Review Board.

Cases of UTI were identified as hospitalisations with a primary diagnosis of pyelonephritis (ICD-9 codes: 590.10, 590.11, 590.2, 590.80, 590.81, 590.9), cystitis (595.0, 595.3, 595.4, 595.89, 595.9) or UTI (599.0). We excluded all records for patients under 18 or that lacked one or more of the explanatory variables (age, sex, primary payer, length-of-stay, admission month, admission year or the hospital identifier). All records with a primary diagnosis code that was not recorded as 590.xx, 595.xx or 599.0 were controls.

Hospitals were geolocated using the US Census Bureau geocoder, and the American Hospital Association (AHA) reported address, city and state. For hospitals that the US Census Bureau failed to locate, the Google Maps Geocoding API was used. Linkage between the AHA-provided address and the events in the NIS was possible using the AHA-hospital identifier (AHA ID). The NIS contains data from 47 of the 50 US states (Alabama, Delaware and Idaho did not contribute) but not all states report hospital identifiers. Of the 47 participating states, 18 do not report the AHA identifier (Alaska, Georgia, Hawaii, Indiana, Kansas, Louisiana, Maine, Michigan, Nebraska, New Mexico, Ohio, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, West Virginia and Wyoming) and one does not report admission month (Florida). Thus, for this study we included data from only 28 of the 50 states (Arizona, Arkansas, California, Colorado, Connecticut, Illinois, Iowa, Kentucky, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, Montana, Nevada, New Hampshire, New Jersey, New York, North Carolina, North Dakota, Oregon,

Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington and Wisconsin). There were 2604 hospitals included in our analysis. The locations of the hospitals used in this analysis are shown in Fig. 1.

Weather definition

Weather data were obtained from the Integrated Surface Dataset (ISD) reported by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration. The mean temperature was computed for each of the weather stations in the NCDC dataset. The temperature was aggregated to the monthly scale. We used weather stations within 100 km of a hospital to compute the average temperature at that hospital in a given month. The average temperature is robust to the exact size of this radius – the values obtained from considering only the nearest station, those within 16.1 km or those within 40.2 km were all highly correlated with those obtained for 100 km ($r > 0.99$).

We opted to use monthly average temperature over monthly average high temperature. The heat advisory and warnings issued in the USA by the National Weather Service are conditioned both on high daytime temperatures and high nighttime temperatures [27]. The lack of nighttime cooling is as important in these heat-related health advisories as the high daytime temperature because high daytime temperatures (e.g. 35 °C) have different effects when the nighttime temperatures are much cooler (e.g. 18–20 °C) vs. still very warm (e.g. 25 °C). Mean monthly temperature does take nighttime relief from heat into account, but mean monthly high temperature does not (26.5–27.5 °C in the first case vs. 30 °C in the second).

Regression model

We regressed whether a given admission was for a UTI on the following explanatory variables: patient age (5-year groups), female sex, primary payer, length-of-stay for that admission, the number of the Elixhauser comorbidities, hospital latitude (binned into ⩽35°N, >35°N ⩽40°N, >40°N ⩽45°N, >45), admission year and
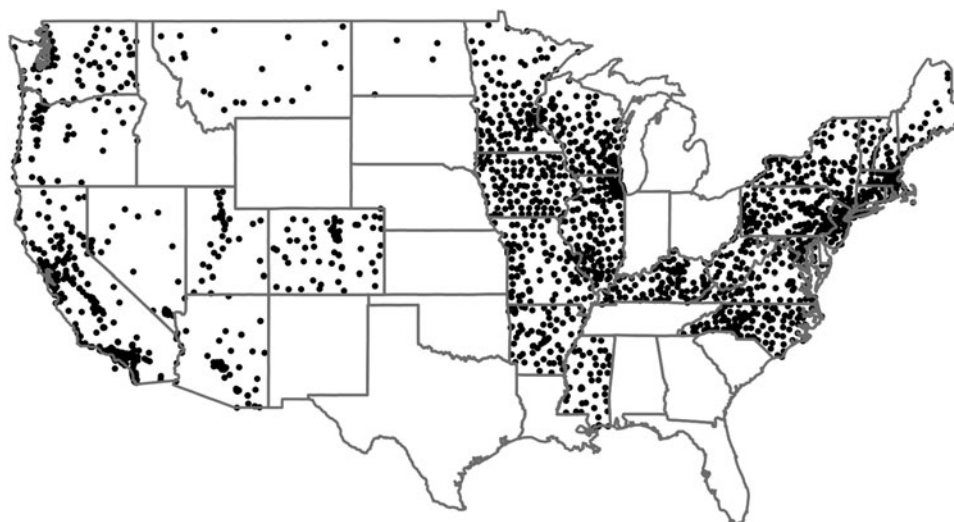
Fig. 1. Locations of 2604 hospitals used in our analysis. Additional states contribute to the NIS project; however, some omit key variables (e.g. Florida does not report month of hospitalisation) while others do not report the hospital's AHA identifier.

the mean temperature in the past month (in 2.5° steps from −5 to 30 °C, as well as under −5 or over 30 °C). Additionally, to account for seasonality not related to weather (e.g. summer travel or excess antibiotic use in the winter), we included a set of month-of-year indicators as fixed effects in our model. Because our outcome is a binary variable, we used logistic regression as our modelling framework. We characterised effects based on point estimates for odds ratios (ORs) and 95% confidence intervals (CIs).

As a measure of the explanatory power of the temperature information, we fit a second model using the same predictors as above but without including temperature. We compared the estimated monthly fixed effects with and without the inclusion of temperature to characterise the seasonality potentially attributable to temperature: in the absence of weather variables, monthly fixed effects will also control for monthly changes in weather.

Results

The NIS from 1998 to 2011 contains information on 108 672 727 hospitalisations, of which 108 648 915 (99.98%) had at least one reported diagnosis. Of those visits, 1 026 959 were for ICD-9 code 599.0 (UTI, site not specified), 19 348 were for 595.x (cystitis) and 36 885 were for 590.x (pyelonephritis) for a total of 1 414 192 cases (1.30% of all visits) and 107 234 723 controls. After requiring the patient to be an adult and to have all of the necessary variables reported, 775 060 (54.8% of starting) cases (180 530 from pyelonephritis, 11 916 from cystitis and 582 614 without a site specified) and 56 515 940 (52.7% of starting) controls remained, for a rate of 1.35%. The vast majority of lost observations occur when we require admission month (not reported by FL) or hospital AHA ID (not reported by 18 states). The sample sizes remaining after applying each of our exclusion criteria are reported in Table 1.

Summary statistics for our sample are detailed in Table 2. Of note, UTI patients were older than non-UTI patients, with a mean age of 68.42 *vs.* 56.71. Correspondingly, many more UTI patients reported Medicare as their primary payer (66.9% *vs.* 43.4%). A larger share of UTI patients was female (71.6% *vs.* non-UTI patients (60.4%). The average outdoor temperature among UTI stays was about 0.6 °C higher than among non-UTI stays (13.26 °C *vs.* 12.62 °C).

Our regression results are shown in Table 3. The odds of an admission being a UTI increased with age (e.g. 61–65-year olds

have 1.48 times greater odds than those 18–25), and women are more likely to be admitted for a UTI than men (OR = 1.73, 95% CI 1.73–1.73). The primary predictor of interest, temperature, shows little change in the odds of an admission diagnosis of a UTI as mean temperature increases from 7.5 to 15 °C. However, the odds of a UTI diagnosis grew with mean temperatures between 15 and 30 °C (1.01–1.19). Relative to months with mean temperatures 5–7.5 °C, admissions in months with average temperatures of 27.5–30 °C have 19% greater odds of being a UTI (95% CI 17–20%). This pattern is most evident when displayed graphically. Figure 2 displays the change in the odds of an admission for a UTI over a range of average monthly temperatures.

To further examine the effect of temperature on UTIs, we compared a model with temperature variables to a model without temperature variables. The estimates of the monthly fixed effects in the summer were significantly reduced in the model that included temperature; see Figure 3. In the model without temperature, the fixed effects describe the entire seasonal process, while in the model with temperature, the fixed effects explain non-temperature-related seasonal processes. Inclusion of temperature reduced the maximum amplitude of the summer spike (August) from 1.23 to 1.06, a decrease of 72%.

Discussion

Using a nationally representative sample, we show that seasonality in the incidence of hospitalisation for UTIs can be explained, in large part, by changes in weather. Specifically, warmer weather is associated with an increase in the odds of admissions for UTIs. Relative to months with average temperatures of 5–7.5 °C, there is a 19% increase in the odds of an admission being diagnosed with a UTI for months where the average temperature is 27.5–30 °C. This increased risk of admission for UTIs persists after adjusting for admission year, admission month, sex, age, payer and even overall patient severity.

With respect to warmer temperatures, we observed a dose–response relationship between temperature and the odds of a diagnosis of UTI until average temperatures exceed 30 °C (see Fig. 1). With average temperatures of 30 °C and over, we found that the odds of admissions for UTIs decreased relative to similarly warm temperatures, which may be caused by changes in behaviour associated with extremely hot weather. Known behaviour changes in response to extremely warm weather include

Table 1. Reductions in sample size after applying exclusion criteria and/or omitting records due to missingness

Filter applied	Sample size (cases)	Sample size (controls)	Per cent of initial sample (cases)	Per cent of initial sample (controls)
None	1 414 192	107 234 723	100	100
Age ⩾ 18	1 279 122	88 908 606	90.45	82.91
Admission month and year reported	1 152 349	80 395 286	81.48	74.97
Length-of-stay reported	1 152 349	80 395 286	81.48	74.97
Sex reported	1 152 349	80 395 286	81.48	74.97
Payer reported	1 149 639	80 168 461	81.29	74.76
AHA ID reported and locatable	775 954	56 552 611	54.87	52.74
⩾1 weather station within 100 km	775 060	56 515 940	54.81	52.70

Table 2. Summary statistics for UTI and non-UTI hospitalisations used in analysis

Variable	Count/Mean		Per cent/SD		P value
	UTI	Control	UTI	Control	
Age	68.42	56.71	20.67	21.06	<0.00001
Female	554 998	34 143 701	71.61	60.41	<0.00001
Length-of-stay	4.55	4.85	5.08	6.82	<0.00001
Number of Elixhauser Comorbidities	0.88	0.81	1.01	1.03	<0.00001
Primary Payer					
Private	136 785	19 422 059	17.65	34.37	<0.00001
Medicaid	77 857	8 108 297	10.05	14.35	<0.00001
Medicare	518 358	24 508 290	66.88	43.37	<0.00001
Uninsured	26 966	2 527 365	3.48	4.47	<0.00001
Other	15 094	1 949 929	1.95	3.45	<0.00001
Latitude	39.37	36.54	3.39	3.42	<0.00001
Month					
Jan	62 153	4 892 222	8.02	8.65	<0.00001
Feb	56 329	4 504 332	7.27	7.97	<0.00001
Mar	61 554	4 925 650	7.94	8.72	<0.00001
Apr	60 859	4 665 173	7.85	8.25	<0.00001
May	64 846	4 769 459	8.37	8.44	0.0837
Jun	65 633	4 684 856	8.47	8.29	<0.00001
Jul	70 522	4 731 883	9.10	8.37	<0.00001
Aug	72 414	4 755 793	9.34	8.41	<0.00001
Sept	67 716	4 609 743	8.74	8.16	<0.00001
Oct	67 611	4 551 929	8.72	8.43	<0.00001
Nov	62 911	4 551 929	8.12	8.05	0.0442
Dec	62 512	4 662 055	8.07	8.25	<0.00001
Monthly mean temperature at admission (°C)	13.26	12.62	9.29	8.76	<0.00001
Monthly mean heat index at admission (°C)	13.21	12.69	8.86	8.87	<0.00001

Comparisons between continuous variables were conducted with a two-sample *t*-test. Comparisons between the categorical variables were for equality of proportion in the given bin and were conducted with a chi-squared test.

alterations in physical and outdoor activities [28]. Additionally, the use of air conditioning during periods of warm weather reduces the potential exposure to very warm temperatures [29]. Thus, the drop-off in risk of UTI admissions may be driven by changes in behaviour during exceptionally warm days. Alternatively, the decrease in risk may be driven by other causes such as adaptation to high temperatures in the warmer regions. People living in regions that routinely experience hot temperatures may be less sensitive to extremely warm weather than people living in generally cooler regions and therefore may be less affected [29]. Such differences may not be captured by our models.

Many infections are seasonal [30]; many are related to weather [31–33]; and some of these are possibly related to changes in climate [34, 35]. Relative to other infections, there are few investigations regarding the seasonality and associations between weather and UTIs. However, our results are consistent with the existing literature. For example, the fraction of visits to Greek primary care physicians for UTI and the temperature in the previous 3 days were strongly correlated [18]. Another study of hospitalisations in New York State found that hot weather was associated with an increase in admissions for renal failure and UTIs [19]. This study used a case-crossover design, where the period some weeks before and after the UTI diagnosis was used to generate controls. They reported a 5°F (2.78 °C) increase in temperature compared with the control periods and sustained over 6 days was associated with a 25% increase in the odds of a UTI admission [19]. Less direct evidence for a relationship between UTI risk and temperature exists. Bloodstream infections, nearly 80% of which started as a UTI, had a relationship with temperature in Olmsted County, MN [36] and Baltimore, MD [37]. In addition, a spike in infections caused by Gram-negative pathogens appeared to be related to temperature in German ICUs [33].

If this relationship between temperature and UTI risk were causal, it may help explain the disagreement between prior work done in the USA and places with more variable climates

Table 3. Logistic regression results for effect of temperature on the odds of a primary diagnosis of UTI, controlling for demographics and other confounders

Variable	Odds ratio	95% CI Lower	95% CI Upper
Age			
18–25	1.00	Ref	Ref
26–30	0.78	0.77	0.78
31–35	0.81	0.80	0.82
36–40	1.03	1.03	1.04
41–45	1.18	1.17	1.19
46–50	1.18	1.17	1.19
51–55	1.25	1.25	1.26
56–60	1.37	1.36	1.38
61–65	1.48	1.47	1.49
66–70	1.51	1.50	1.52
71–80	2.16	2.15	2.18
81+	3.78	3.75	3.80
Female	1.73	1.73	1.73
Payer			
Medicare	1.00	Ref	Ref
Medicaid	0.90	0.89	0.90
Private insurance	0.63	0.63	0.64
Uninsured	1.09	1.08	1.10
Other	0.73	0.72	0.73
Admission month			
January	1.00	Ref	Ref
February	0.98	0.97	0.98
March	0.96	0.96	0.97
April	1.00	0.99	1.01
May	1.01	1.00	1.01
June	0.99	0.98	1.00
July	1.03	1.03	1.04
August	1.06	1.05	1.07
September	1.06	1.05	1.07
October	1.08	1.08	1.09
November	1.07	1.07	1.08
December	1.05	1.04	1.05
Year	1.02	1.02	1.02
LOS	0.97	0.97	0.97
Number of Elixhauser comorbidities	1.03	1.03	1.03
Latitude			
⩽35° N	1.00	Ref	Ref
35°N to 40°N	0.95	0.94	0.95
40°N to 45°N	0.91	0.90	0.91
>45°N	0.87	0.86	0.87

(Continued)

Table 3. (*Continued.*)

Variable	Odds ratio	95% CI Lower	95% CI Upper
Mean temperature (°C)			
Under −5	0.91	0.91	0.92
−5 to −2.5	0.97	0.96	0.98
−2.5 to 0	0.97	0.97	0.98
0–2.5	0.99	0.99	1.00
2.5–5	1.01	1.00	1.01
5–7.5	1.00	Ref	Ref
7.5–10	1.00	0.99	1.00
10–12.5	0.99	0.99	1.00
12.5–15	1.01	1.01	1.02
15–17.5	1.05	1.04	1.06
17.5–20	1.09	1.08	1.10
20 to 22.5	1.13	1.12	1.14
22.5–25	1.16	1.15	1.16
25–27.5	1.15	1.14	1.16
27.5–30	1.19	1.17	1.20
30+	1.12	1.11	1.14

and warmer summers that have identified seasonality, and places such as Sweden [20, 23] and Norway [21, 22] with cooler summers where the incidence of seasonality has not been described. For instance, a typical July average temperature in Oslo is 16 °C and London is 19 °C, both of which fall towards the lower portion of the dose–response relationship described by our model. In contrast, US cities have much warmer July average temperatures. For instance, St. Louis has an average July temperature of 27 °C. Thus, in the absence of these high summer temperatures, seasonality of UTIs may be reduced, thus explaining the lack of seasonality observed in Scandinavia, the UK and Netherlands [20–25].

Although there may be alternative explanations for the association between UTIs and warmer temperatures, a biologically plausible hypothesis is that increased temperatures may lead to volume depletion, thereby leading to decreased urinary volume and flow. In turn, decreased urinary flow can hamper the removal of bacteria from the urinary tract [11], thus increasing the potential for a UTI [11]. Alternatively, more concentrated urine may increase the likelihood of developing a UTI. Although the relationship between dehydration and fluid intake and UTI is somewhat controversial [11, 38, 39], some studies have shown that increasing hydration can decrease the risk of UTIs. For example, a study of Finnish school teachers found that among the half that limited drinking water at work to avoid using the restroom, the odds of developing a UTI were 2.2 times larger than among their more hydrated peers [10]. Another case–control study found that cases drank less water and voided less frequently than controls [40]. Also, another study found that adjusting fluid intake according to urine osmolality [12] was associated with a reduced risk of UTIs. Thus, even limited volume depletion from warmer temperatures may be sufficient to significantly increase the risk of developing a UTI.
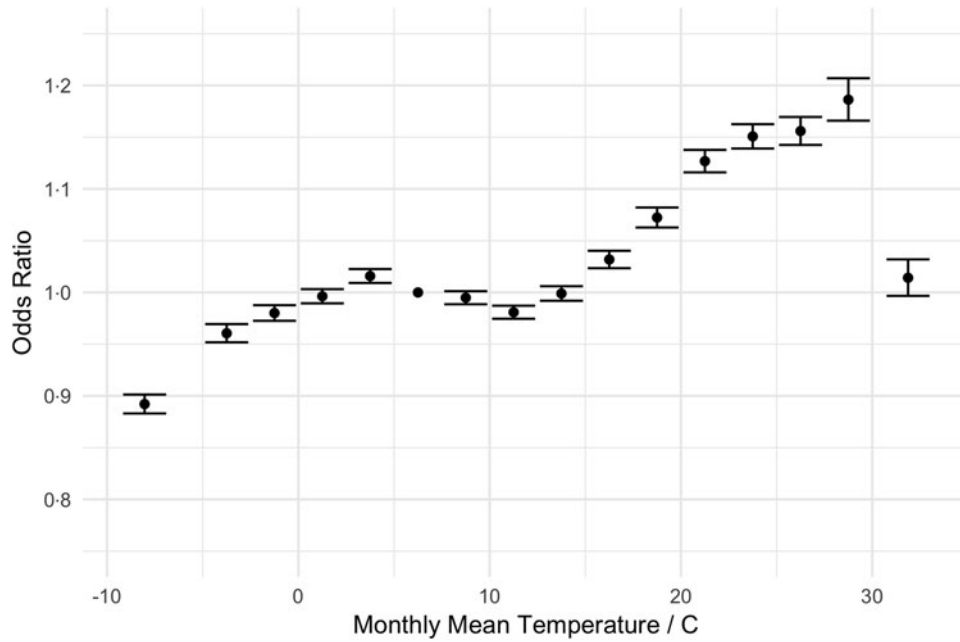
Fig. 2. Adjusted odds ratios (ORs) for diagnosis of UTI as a function of temperature (graphical display of data in Table 3). The dot denotes the point estimate of the OR and the error bars reflect the 95% CI about that estimate. ORs are adjusted for year, month-of-year, climate and demographic factors.

Our results have health implications for alerts related to temperature, especially for women at high risk for UTIs, as many women suffer from recurrent UTIs [7, 41–43]. Currently, the National Weather Service in the United States issues a Heat Advisory when both the maximum heat index will be over 38 °C and the nighttime temperatures remain above 24 °C for two or more days. An Excessive Heat Warning is issued when the maximum heat index temperature is forecast to be above 41 °C with nighttime lows above 24 °C for two or more days [27]. However, people may already alter their behaviour at these high temperatures – perhaps even without the warnings. Yet based on our results, more moderate temperatures – average temperatures of 22.5–30 °C – are where the greatest risk of UTIs from environmental exposures may exist. Thus, interventions may need to focus on less-extreme temperatures in order to moderate the effects of temperature on UTIs by either maintaining
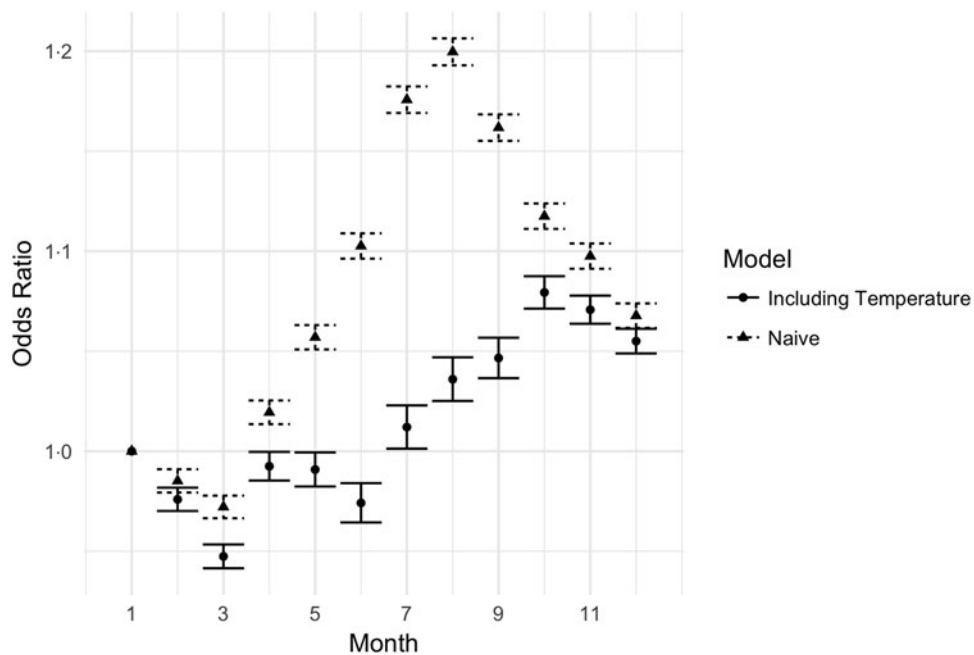
Fig. 3. Monthly odds ratios for UTI in models with and without temperature included. The triangles reflect the estimated monthly effects for a model including year, month-of-year, climate and demographics, but not including the mean monthly temperature. The circles are the estimated monthly effects in a model with temperature data included. The error bars are 95% CIs.

hydration or avoiding exposure to warm weather situations that could lead to volume depletion.

In recent decades, much attention in the field of infectious diseases has been focused on global warming or climate change [32, 34, 35, 44, 45]. Many have speculated that warmer temperatures could increase many different infections, especially potentiating the spread of vector-borne disease, as vectors spread to new locations when temperatures rise (e.g. tick-borne diseases in Canada) [32, 44–46]. Our results indicate that if temperatures consistently increase, the odds of UTIs may also increase at a population level. However, our findings also indicate that behaviour changes may help ameliorate the risk of warmer weather with UTIs. Adopting such changes may be more difficult in some locations, for example, in locations without a high penetration of air conditioning or a lack of clean drinking water.

Our results show that a substantial portion of the seasonality in UTI hospitalisation incidence may be attributed to temperature. The residual seasonality in UTI hospitalisation incidence may be due to factors other than temperature. However, it is also likely that because we aggregate weather and UTI incidence to the monthly level, we may not be able to explain as much UTI seasonality as if we had more granular data (e.g. date-of-admission). This is a limitation of our data. Although our temperature data are very granular, the NIS only reports the month of the hospitalisation, and we are forced to aggregate temperature to the monthly scale as a result.

One potential limitation of our work is that we selected dry bulb temperature as our measure of weather and did not include other factors related to both perceived temperature and the physiological response to heat such as humidity. However, repeating our analysis using heat index, a measure that combines temperature and humidity to estimate the perceived temperature on a reference human [47], does not change our results (estimated ORs for the dose–response relationship of UTI admission with heat indices from 10 to 30 °C range from 1.00 to 1.17, and decrease to 1.14 for heat indices over 30 °C). We opted to focus our results on dry bulb temperature as the models gave similar results.

A limitation to the generalisability of our results is our focus on hospitalisations with a primary diagnosis of ICD-9-CM 590.xx, 595.xx and 599.0. We made this study design choice made to restrict the sample to admissions for UTI and to reduce the potential heterogeneity introduced by including secondary diagnoses for UTI, which may have developed during hospital admissions (e.g. catheter-associated UTIs). However, as a result, our descriptions of temperature-dependent seasonality may not apply to more UTIs that may cause other syndromes requiring hospitalisation (e.g. sepsis), where the diagnosis of UTI might not have been coded as the primary reason for admission. The extent to which our results do or do not generalise to these populations will need to be addressed by future investigation. An addition limitation regarding the generalisability of our results relates to our study being restricted to only UTIs resulting in hospitalisation. UTIs are largely treated on an outpatient basis, and it is possible that this restriction leads to selection effects and may not hold for less severe cases of UTIs not requiring hospital admission. Finally, our study uses administrative (i.e., billing) data and do not have any information about medications, test results or microbiological data. Thus, we cannot examine, for example, if pathogens responsible for UTIs or treatments for UTIs change with the seasons.

Despite limitations associated with our investigation, we demonstrate a strong, dose-dependent and biologically plausible relationship between average temperature and UTI risk. Admissions at hospitals in warm months (temperatures of 22.5–30 °C) have odds of being diagnosed as a UTI that are up to 1.19 times larger than in cooler months (temperatures of 5–7.5 °C). Our results may help explain the pathogenesis of UTIs and help identify new risk factors in specific populations. More temperature-based investigations are needed both at the population level with more granular data (e.g. daily data) and at an individual level.

References

1. **Nicolle LE** (2002) Epidemiology of urinary tract infections. *Clinical Microbiology Newsletter* **24**(18), 135–140.
2. **Gupta K, et al.** (2011) International clinical practice guidelines for the treatment of acute uncomplicated cystitis and pyelonephritis in women: a 2010 update by the Infectious Diseases Society of America and the European Society for Microbiology and Infectious Diseases. *Clinical Infectious Diseases* **52**(5), e103–e120.
3. **Zilberberg MD and Shorr AF** (2013) Secular trends in gram-negative resistance among urinary tract infection hospitalizations in the United States, 2000–2009. *Infection Control & Hospital Epidemiology* **34**(9), 940–946.
4. **Simmering JE, et al.** (2017) The increase in hospitalizations for urinary tract infections and the associated costs in the US, 1998–2011. *Open Forum Infectious Diseases* **4**(1), ofw281.
5. **Olson RP, Harrell LJ and Kaye KS** (2009) Antibiotic resistance in urinary isolates of *Escherichia coli* from college women with urinary tract infections. *Antimicrobial Agents and Chemotherapy* **53**(3), 1285–1286.
6. **Foxman B** (2002) Epidemiology of urinary tract infections: incidence, morbidity, and economic costs. *Journal of American Medicine* **8**(113), 5S–13S.
7. **Scholes D, et al.** (2000) Risk factors for recurrent urinary tract infection in young women. *Journal of Infectious Diseases* **182**(4), 1177–1182.
8. **Hooton TM, et al.** (1996) A prospective study of risk factors for symptomatic urinary tract infection in young women. *New England Journal of Medicine* **468**(7), 468–474.
9. **Pitt M** (1988) Fluid intake and urinary tract infection. *Nursing Times* **85**(1), 36–38.
10. **Nygaard I and Linder M** (1997) Thirst at work: an occupational hazard? *International Urogynecology Journal* **8**(6), 340–343.
11. **Beetz R** (2003) Mild dehydration: a risk factor of urinary tract infection? *European Journal of Clinical Nutrition* **57**(2), 52–58.
12. **Eckford S, et al.** (1995) Hydration monitoring in the prevention of recurrent idiopathic urinary tract infections in pre-menopausal women. *British Journal of Urology* **76**(1), 90–93.
13. **Anderson JE** (1983) Seasonality of symptomatic bacterial urinary infections in women. *Journal of Epidemiology and Community Health* **37**, 286–290.
14. **Stamm WE, et al.** (1991) Natural history of recurrent urinary tract infections in women. *Reviews of Infectious Diseases* **13**(1), 77–84.
15. **Czaja CA, et al.** (2007) Population-based epidemiologic analysis of acute pyelonephritis. *Clinical Infectious Diseases* **45**(3), 273–280.
16. **Rossignol L, et al.** (2013) A method to assess seasonality of urinary tract infections based on medication sales and Google Trends. *PLoS ONE* **8**(10), e76020.
17. **Freeman JT, Anderson DJ and Sexton DJ** (2009) Seasonal peaks in *Escherichia coli* infections: possible explanations and implications. *Clinical Microbiology and Infection* **15**(10), 951–953.
18. **Falagas ME, et al.** (2009) Effect of meteorological variables on the incidence of lower urinary tract infections. *European Journal of Clinical Microbiology & Infectious Diseases* **28**(6), 709–712.

19. **Fletcher BA, *et al*.** (2012) Association of summer temperatures with hospital admissions for renal diseases in New York state: a case-crossover study. *American Journal of Epidemiology* **175**(9), 907–916.

20. **Ferry S, Burman LG and Mattsson B** (1987) Urinary tract infection in primary health care in northern Sweden. I. Epidemiology. *Scandinavian Journal of Primary Health Care* **5**(2), 123–128.

21. **Vorland LH, Carlson K and Aalen O** (1985) An epidemiological survey of urinary tract infections among outpatients in northern Norway. *Scandinavian Journal of Infectious Diseases* **17**(3), 277–283.

22. **Vorland L, Carlson K and Aalen O** (1985) Antibiotic resistance and small R plasmids among *Escherichia coli* isolates from outpatient urinary tract infections in northern Norway. *Antimicrobial Agents and Chemotherapy* **27**(1), 107–113.

23. **Eriksson A, Giske CG and Ternhag A** (2013) The relative importance of *Staphylococcus saprophyticus* as a urinary tract pathogen: distribution of bacteria among urinary samples analysed during 1 year at a major Swedish laboratory. *APMIS* **121**(1), 72–78.

24. **Kwok W-Y, *et al*.** (2006) Incidence rates and management of urinary tract infections among children in Dutch general practice: results from a nation-wide registration study. *BMC Pediatrics* **6**(1), 10.

25. **Stansfeld J** (1966) Clinical observations relating to incidence and aetiology of urinary-tract infections in children. *British Medical Journal* **1**(5488), 631.

26. **Pead L, Maskell R and Morris J** (1985) Staphylococcus saprophyticus as a urinary pathogen: a six year prospective survey. *British Medical Journal (Clinical Research Ed)* **291**(6503), 1157–1159.

27. **National Weather Service NOaAA** (2017) Heat Watch. http://www.nws.noaa.gov/om/heat/ww.shtml.

28. **McCormack GR, *et al*.** (2010) Sex-and age-specific seasonal variations in physical activity among adults. *Journal of Epidemiology and Community Health* **64**(11), 1010–1016.

29. **Barreca A, *et al*.** (2016) Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the twentieth century. *Journal of Political Economy* **124**(1), 105–159.

30. **Fisman DN** (2007) Seasonality of infectious diseases. *Annual Review of Public Health* **28**, 127–143.

31. **Fisman DN, *et al*.** (2005) It's not the heat, it's the humidity: wet weather increases legionellosis risk in the greater Philadelphia metropolitan area. *Journal of Infectious Diseases* **192**(12), 2066–2073.

32. **Greer A, Ng V and Fisman D** (2008) Climate change and infectious diseases in North America: the road ahead. *Canadian Medical Association Journal* **178**(6), 715–722.

33. **Schwab F, Gastmeier P and Meyer E** (2014) The warmer the weather, the more gram-negative bacteria – impact of temperature on clinical isolates in intensive care units. *PLoS ONE* **9**(3), e91105.

34. **De Souza DK, Owusu PN, Wilson MD** (2012) Impact of climate change on the geographic scope of diseases. In Chhetri N, ed. *Human and Social Dimentions of Climate Change*, Intech, pp. 245–264.

35. **Rohayem J** (2009) Norovirus seasonality and the potential impact of climate change. *Clinical Microbiology and Infection* **15**(6), 524–527.

36. **Al-Hasan MN, *et al*.** (2009) Seasonal variation in *Escherichia coli* bloodstream infection: a population-based study. *Clinical Microbiology and Infection* **15**(10), 947–950.

37. **Perencevich EN, *et al*.** (2008) Summer peaks in the incidences of gram-negative bacterial infection among hospitalized patients. *Infection Control and Hospital Epidemiology* **29**(12), 1124–1131.

38. **Remis RS, *et al*.** (1987) Risk factors for urinary tract infection. *American Journal of Epidemiology* **126**(4), 685–694.

39. **Lotan Y, *et al*.** (2013) Impact of fluid intake in the prevention of urinary system diseases: a brief review. *Current Opinion in Nephrology and Hypertension* **22**(Suppl. 1), S1–S10.

40. **Ervin C, Komaroff AL and Pass TM** (1980) Letter on behavioral factors and urinary tract infections. *JAMA* **243**(4), 330–331.

41. **Fihn SD** (2003) Acute uncomplicated urinary tract infection in women. *New England Journal of Medicine* **349**, 259–266.

42. **Foxman B, *et al*.** (2000) Urinary tract infection: self-reported incidence and associated costs. *Annals of Epidemiology* **10**(8), 509–515.

43. **Gupta K, *et al*.** (2001) Patient-initiated treatment of uncomplicated recurrent urinary tract infections in young women. *Annals of Internal Medicine* **135**(1), 9–16.

44. **Hay SI, *et al*.** (2002) Climate change and the resurgence of malaria in the east african highlands. *Nature* **415**(6874), 905–909.

45. **Ogden N, *et al*.** (2006) Climate change and the potential for range expansion of the Lyme disease vector Ixodes scapularis in Canada. *International Journal for Parasitology* **36**(1), 63–70.

46. **Gubler DJ, *et al*.** (2001) Climate variability and change in the United States: potential impacts on vector-and rodent-borne diseases. *Environmental Health Perspectives* **109**(Suppl. 2), 223.

47. **Rothfusz LP** (1990) The heat index equation (or, more than you ever wanted to know about heat index). Fort Worth, Texas: National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology, 9023.