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The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia

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Background A rarely investigated consequence of heat exposure is renal dysfunction resulting from dehydration and hyperthermia. Our study aims to quantify the relationship between exposure to extreme high temperatures and renal morbidity in South Australia.

Methods Poisson regression accounting for over dispersion, seasonality and long-term trend was used to estimate the effect of heat waves on hospital admissions for renal disease, acute renal failure and renal dialysis over a 12-year period. Selected comorbidities were investigated as possible contributing risk factors.

Results Admissions for renal disease and acute renal failure were increased during heat waves compared with non-heat wave periods with an incidence rate ratio of 1.100 [95% confidence intervals (CI) 1.003–1.206] and 1.255 (95% CI 1.037–1.519), respectively. Hospitalizations for dialysis showed no corresponding increase. Comorbid diabetes did not increase the risk of renal admission, however 'effects of heat and light' and 'exposure to excessive natural heat' (collectively termed effects of heat) were identified as risk factors.

Conclusion Our findings suggest that as heat waves become more frequent, the burden of renal morbidity may increase in susceptible individuals as an indirect consequence of global warming.

Keywords Acute renal failure, heat waves, global warming, kidney disease, weather

Introduction

One of the consequences of global warming is an increase in the frequency and intensity of heat waves. With well-documented increases in morbidity and mortality associated with heat waves, it is likely that the incidence of heat-associated adverse health outcomes will escalate unless population adaptation occurs.[1] Exposure to extreme hot weather can induce heat-related conditions including hyperthermia and heat stress in susceptible individuals, whilst the thermoregulatory physiological and circulatory adjustments necessary to cope with extreme heat can place stress on the kidneys[2] and compromise the function of the renal system.

Several northern hemisphere studies have reported increases in hospital admissions for renal dysfunction during periods of high ambient temperatures.[2–6] During August 2003, the extreme heat wave across Europe resulted in mortalities in many countries including Portugal and the United Kingdom where

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over 2000 excess deaths occurred.[7] Worst affected with some 14 729 excess deaths was France,[8] where it has been suggested that many of the elderly decedents were dehydrated and had evidence of renal failure.[9] Other studies investigating the same heat event in Italy reported that all patients affected by hyperthermia experienced renal failure shortly after admission[10] and that severe renal diseases were amongst the prominent causes of excess mortality among the elderly.[11] Additionally acute renal failure (ARF), often associated with exposure to extreme heat[2,6,12,13] may have serious consequences including death.[14] Those at risk of developing renal dysfunction during hot weather include the elderly[9,15] and those with chronic medical conditions including diabetes.[2,12,14]

Australia regularly experiences periods of extreme heat during summer and an increased frequency of heat waves is predicted with climate change.[16,17] However, to date, there have been few reports in the literature about heat-aggravated illnesses in Australia and, despite the biological plausibility, none investigating heat-triggered renal diseases. This study aims to determine if, in a temperate climate, a relationship exists between exposure to extreme heat and renal morbidity, by investigating hospital admissions for renal disease and ARF during heat waves, and the influence of comorbidities.

Methods

The analysis was based on data from the city of Adelaide, South Australia, with a population of 1.15 million.[18] Adelaide is situated within the temperate zone[19] lying at latitude 34°55′ S, longitude 138°35′ E, near the Southern Central Australia. With influences of heat and aridity from the north and moisture and coolness from the south and west, Adelaide has hot dry summers and mild winters. January and February are the warmest months with mean maximum temperatures of ~29°C. Heat waves regularly occur during summer with temperatures often exceeding 40°C.

Hospital admissions data for the Adelaide metropolitan area were obtained for the period January 1, 1995 to December 31, 2006 from the South Australian Department of Health. Discharge diagnoses were accessed using the Integrated South Australian Activity Collection (ISAAC), an official collection of admitted patient activity in the State's public and private hospitals.[20] Data relating to individuals who resided outside of the Adelaide metropolitan area were excluded from the study.

Diseases were classified according to the International Classification of Diseases, 10th revision,[21] Australian modification (ICD-10-AM). For admissions occurring earlier in the study period, coding was reclassified from ICD-9 to ICD-10. Daily counts of admissions with principal discharge diagnoses of renal disease (N00–N39) were accessed. In an attempt to characterize renal morbidity during heat waves, we chose to include ARF (N17) and renal dialysis not otherwise specified (Z49.1), as being representative of acute and chronic disease aetiology, respectively. Chosen on the basis of biological plausibility and previous studies[2,12,22,23] specific secondary contributing diagnoses including diabetes (E10–E14) were investigated. Additionally, to investigate possible associations with heat exposure,[24] the classifications 'exposure to excessive natural heat' (X30) and 'effects of heat and light' (T67) (incorporating hyperthermia, heatstroke and heat exhaustion), were combined and collectively termed 'effects of heat'. Data were stratified by gender and 5 year age groups initially, and subsequently age groups comprising children (0–14 years), adults (15–64 years) and the elderly (65 years and over).

Climatic data for the study period were obtained from the Australian Bureau of Meteorology. Daily maximum and minimum ambient air temperatures for Adelaide were accessed from a monitoring station near the central business district, the site considered to best represent conditions across the metropolitan area. Heat waves were defined as being three or more consecutive days when daily maximum temperatures reached or exceeded 35°C, the 95th percentile of the maximum temperature range for the study period (Table 1). Seasons were defined as cool (from April 1 to October 31) and warm (from November 1 to March 31).

Data analyses

The relation between daily renal admissions and maximum temperature was explored graphically using a lowess (locally weighted regression) smoother[25] with a bandwidth of 0.8, utilizing 80% of the data. Secular trends of admissions over time were identified in a similar manner. A Poisson distribution was assumed for the count data of hospital admissions. Using a case

Table 1 Summary statistics of daily temperatures (°C) for Adelaide, 1995–2006

	Maximum temperatures			**Minimum temperatures**		
Period	Mean	5th percentile	95th percentile	Mean	5th percentile	95th percentile
1995–2006	22.3	14.1	35.3	12.2	5.1	21.3
Cool	18.7	13.5	27.3	9.7	4.4	15.6
Warm	27.4	19.3	38.0	15.7	10.1	24.0
Heat waves	38.0	35.2	41.9	23.1	17.5	28.3

series approach,[26] conditional fixed effects Poisson regression models were used to quantify the association between daily counts of renal admissions and heat waves during the warm season. Risk periods were predefined heat wave periods and the referent period was all non-heat wave days in the warm season. A goodness-of-fit test was applied to each model and if over dispersion was detected, as often occurs with recurrent events, a negative binomial regression model was fitted.[27] Seasonality was controlled for by exclusion of the cool season[28] and analysis conducted within years adjusted for long-term trends.[26]

All statistical analyses were conducted using Stata v9.2.[25] A significance level of 0.05 was adopted for each test. Results for the Poisson models are expressed as incidence rate ratios (IRR) with 95% confidence intervals (CIs).

Results

The mean maximum daily temperature in Adelaide during the study period was 22.3°C (Table 1), with the corresponding mean maximum temperatures during the cool season, warm season and heat waves being 18.7°C, 27.4°C and 38.0°C, respectively. The highest recorded temperature was 44.3°C on February 14, 2004 during an 8-day heat wave and an extreme heat event occurred in January 2006 with four continuous days over 40°C. A total of 31 heat waves were recorded occurring in 10 of the 12 years, with a maximum of six heat waves in 1 year. The duration of individual heat waves ranged from 3 to 8 days, with a mean of 3.8 days.

Renal disease

Over the study period, there were 90 720 hospital admissions for renal disease (N00–N39). Compared with non-heat wave periods, a 10% increase in renal admissions was observed during heat waves (Table 2). Age-specific analysis showed that individuals aged 15–64 years had an IRR of 1.130 (95% CI 1.025–1.247) with increases in both male and female admissions (Table 2). The very elderly (85+ years) had the highest overall estimate of effect with females of this age having an IRR of 1.218 (95% CI 1.022–1.453).

Acute renal failure

There were 3579 admissions for ARF (N17) over the study period, representing 3.9% of all renal disease admissions. The risk of ARF was markedly increased during heat wave periods compared with control periods in the warm season. As shown in Table 3, the overall IRR for admission with ARF during heat waves compared with non-heat wave periods was 1.255 (95% CI 1.037–1.519). The risk was greatest in males (IRR 1.350, 95% CI 1.049–1.736), specifically males aged 15–64 years (IRR 1.786, 95% CI 1.169–2.730).

During the summer of 2004, three heat waves occurred within four weeks in Adelaide. Figure 1 shows ARF admissions and temperatures in Adelaide during February and March. It can be seen that trends are often similar, with a short delay between high temperatures and a rise in admissions. The figure demonstrates admissions peaking during an extreme heat event when the maximum temperature reached 44.3°C.

Dialysis

There were 501 197 admissions for extracorporeal dialysis (Z49.1) over the study period. Our results showed no association of admissions with heat waves compared to non-heat wave periods in the warm season (Table 3).

Table 2 The IRR of hospital admissions for renal disease during heat wave periods compared with non-heat wave periods in the warm season

Age	Gender	H/W	Non-H/W	Total	IRR (95% CI)	*P*-value
All		2796	87 924	90 720	1.100 (1.003–1.206)	0.043
	Male	1419	43 842	45 261	1.106 (0.981–1.247)	0.098
	Female	1377	44 082	45 459	1.088 (1.029–1.151)	0.003
15–64 years		1534	45 891	47 425	1.130 (1.025–1.247)	0.014
	Male	775	22 558	23 333	1.146 (0.986–1.333)	0.075
	Female	759	23 333	24 092	1.098 (1.018–1.184)	0.015
65+ years		1137	37 062	38 199	1.086 (0.978–1.205)	0.121
	Male	583	19 035	19 618	1.051 (0.922–1.199)	0.458
	Female	554	18 027	18 581	1.085 (0.993–1.186)	0.070
85+ years		213	6455	6668	1.196 (1.036–1.380)	0.014
	Male	71	2426	2497	1.046 (0.817–1.340)	0.719
	Female	142	4029	4171	1.218 (1.022–1.453)	0.028

The counts of admissions by age group and gender during heat wave (H/W) and non-heat wave (Non-H/W) periods and over the whole study period (total) are shown.

Table 3 The effect of heat waves on hospital admissions for renal disorders and comorbidities, showing IRR, 95% CIs and *P*-values

Indication	ICD-10-AM code	IRR (95% CI)	*P*-value
Renal disease	N00–N39	1.100 (1.003–1.206)	0.043
ARF	N17	1.255 (1.037–1.519)	0.019
Dialysis	Z49.1	1.013 (0.969–1.059)	0.564
Renal disease with coexisting diabetes	E10–E14	0.945 (0.797–1.121)	0.517
Renal disease with coexisting effects of heat	T67, X30	10.971 (2.065–58.292)	0.005

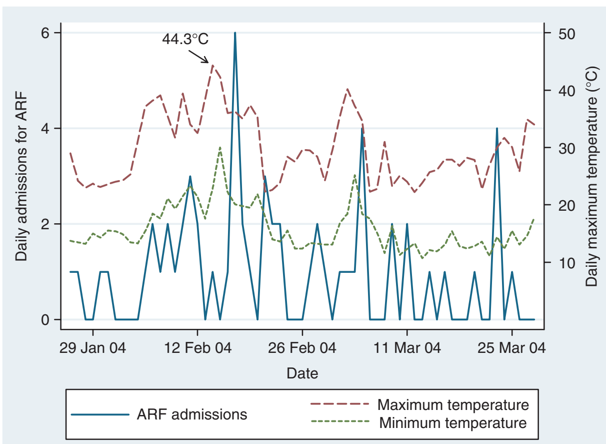

Figure 1 The relationship between daily hospital admissions for ARF and temperature during February and March 2004 when three heat waves were recorded

Comorbidities

Renal admissions for persons with contributing discharge diagnoses of diabetes (E10–E14) showed no overall increase during heat waves compared with control periods, as seen in Table 3. Only females aged 50–54 years and 85+ years with comorbid diabetes had a notably increased risk of admission for renal disease during heat waves.

Conversely, renal admissions with comorbid effects of heat (X30, T67) were increased almost 11-fold during heat waves (Table 3). However, estimates in this group are compromised due to the small sample size ($N = 9$).

Discussion

This study is the first to specifically investigate the association between high ambient temperatures and hospital admissions for renal disease in a temperate Australian climatic region. In addition to admissions attributed to diseases of renal aetiology, we specifically investigated those attributed to ARF and extracorporeal dialysis, and those with comorbid diabetes or indications of heat exposure. Our results showed that during the warm season, the risk of hospital admission for renal disease was increased during heat waves compared with non-heat wave periods, with highest effect seen in admissions for ARF. Extracorporeal dialysis, a regularly scheduled treatment for sufferers of chronic renal disease or end-stage renal failure, involves multiple booked admissions unlikely to be affected by climatic conditions. Not unexpectedly, no association was found between admissions for dialysis and heat waves.

Studies of heat wave morbidity and mortality elsewhere have provided evidence of renal impairment attributed to heat exhaustion and heat stroke.[4,6,9,29] That an association exists between exposure to extreme heat and kidney dysfunction is biologically plausible. As a consequence of hyperthermia and dehydration, the body's physiological mechanisms attempt to regulate electrolyte and water imbalance. As glomerular filtration rates decrease renal failure can occur. The elderly are more vulnerable to the development of heat-related renal disease due to lowered thermotolerance, impaired thirst sensation,[9,11] diminished conservation of sodium and water during dehydration, and reduced glomerular filtration rates.[9,15] Indeed, our results showed that the very elderly (85+ years) were the age group with the highest risk of renal admission during heat waves with effect estimates highest for females. Additionally we found that individuals in the 15–64 year age group were also at risk. Reasons for the susceptibility of persons in this younger age group remain purely speculative, although occupational and recreational activities in the heat may be behavioural risk factors in this age group.

Many therapeutic drugs can be risk factors for heat-related illness and subsequent renal involvement, due to their ability to inhibit thermoregulation in various ways (e.g. altered sweat production, dehydration, increased heat production, impaired thirst recognition or inhibited heat loss). These include many psychotropic drugs including neuroleptics, anxiolytics, antidepressants and anti-cholinergics commonly used in the treatment of mental and cognitive disorders, as well as anti-hypertensives (including β-blockers), diuretics, barbiturates and anti-histamines.[6,9,11,30] Additionally, the use of multiple medications, often prescribed to the chronically ill and the elderly, is also a risk factor.[15] Information regarding medication histories, however, was unavailable given our ecological study design.

Increases in hospital admissions for ARF due to heat exposure were a consequence of the 1995 heat wave in Chicago, USA.[2,12] Similarly, we found that ARF admissions were markedly increased during heat waves with males being at greatest risk as confirmed by other studies.[14]

There were very few instances where renal disease was recorded as the principal diagnosis and effects of heat as a secondary diagnosis, making analysis problematic. It is possible that our criterion was too specific, or that cases of heat-related illness are simply miscoded or under-reported as has been suggested by other authors.[24,29,31] Definitions of heat illnesses are generally inconsistent, with incidences of heat exhaustion, heat stroke and other related conditions often being attributed to more common diagnoses.[24] Consequently, such under-reporting can result in imprecise data on the health effects of heat.[29] Conversely, it is possible in climates where heat waves are uncommon, that differential coding between heat wave and non-heat wave periods may occur, resulting in conditions more likely to be coded as heat-related during times of extreme heat, particularly if heat-health alerts are issued locally.

A descriptive survey of emergency hospital presentations in Adelaide during a 10-day heat wave just 2 years prior to our study period (February 1993) revealed a total of 94 patients diagnosed with heat-related illness, 78% with heat exhaustion and 15% with heat stroke.[15] Plasma creatinine and plasma urea concentrations, biochemical indicators of renal dysfunction,[4,29] were abnormal in 67% and 64% of these patients, respectively. It is possible that both renal dysfunction and effects of heat were not recorded on discharge summaries despite both being contributing clinical factors. This would explain why so few instances of effect of heat were listed as secondary diagnoses for renal admissions in the 12 years of our study, thereby highlighting major discrepancies in classification of diagnoses, and potential flaws in a system which specifies coding on discharge, not admission. This study also noted the role of high minimum as well as maximum temperatures prior to the onset of heat-related illnesses, a factor also considered by other authors.[22,23]

Reports have shown that persons with diabetes have an increased susceptibility to extreme heat[2,13,22,32] and heat-related renal dysfunction,[12] possibly due to pre-existing renal conditions resulting in compromised kidneys.[13,33] In contrast to other studies, our results showed no overall increase during heat waves of renal admissions with diabetes as a comorbidity, possibly due to acclimatization and heat awareness of the diabetic population in Adelaide. There is a suggestion, however, of increased susceptibility in very elderly females with diabetes. It should be noted that we did not investigate if total admissions for persons with diabetes were increased during heat waves.

There are several limitations to this study. First, we identified conditions using primary or secondary discharge diagnoses using ICD coding of discharge diagnoses and the possibility of miscoding cannot be overlooked. Accuracy of epidemiological heat-related morbidity studies is likely to be greater using individual case-note audits of emergency department admissions. Similarly, we were unable to ascertain, using de-identified data, those dialysis admissions whose condition became acute on chronic due to the effects of heat exposure. Second, although our findings are reinforced by those of others,[2,6,12] the relatively small number of admissions for ARF in our study dictates cautious interpretation of results. Given the potentially serious consequences and high mortality,[14] further research with larger sample sizes is warranted to identify incidence and risk factors for heat-triggered ARF in Australia. Finally, we did not control for day of the week or Christmas holidays, factors which may determine daily activities, population mobility and consequential exposure levels during the Australian summer, thereby introducing the possibility of information bias.

Conclusion

In accordance with global warming trends reported worldwide, temperatures in Adelaide are gradually rising. According to the Intergovernmental Panel on Climate Change, 11 of the 12 years 1995–2006 ranked amongst the 12 warmest on record globally.[16] In Australia, maximum temperatures have increased by 0.15°C per decade since 1950, and more so in South Australia (0.21°C per decade), indicating that the state is warming at a faster rate than national trends. Adelaide's summer temperatures are predicted to rise by 0.4–0.9°C by 2030 and up to 2.1°C by 2070, even higher if CO_2 emissions are not stabilized.[34] Currently, the city experiences approximately 10 summer days exceeding 35°C annually, and with extreme heat events likely to increase in frequency,[35] predictions suggest this could increase to 13–28 days by 2070.[36]

By using current data to predict future scenarios, our results suggest the burden of renal morbidity may increase as periods of hot weather become more frequent and the population ages. With long-term treatment options for renal disease, particularly ARF, being costly and resource intense, an increase in incidence will have significant public health implications. Health authorities may need to address the availability of renal facilities and strategies for the mitigation of heat-related renal disease including health promotion programmes to encourage adequate hydration during extreme heat.

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Conflict of interest: None declared.

KEY MESSAGES

- The objective of this article was to assess the impact of extreme heat on hospital admissions for renal disease and in particular, acute renal failure, in a temperate Australian climate.
- We found the incidence of both conditions to be increased in association with heat waves, particularly acute renal failure.
- Further research is warranted in this area to investigate preventive measures to avert climate change induced heat-related illnesses with the potential for serious renal involvement.

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Commentary: Our next challenge in heatwave prevention

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The terrible health impact of the 2003 heatwave was a trauma for Europe. Since then, several European countries have massively invested in the preparation of warning systems and appropriate heatwave prevention plans.[1] Most of these plans are targeted towards a reduction of the short-term mortality. Indeed, the study of the 2003 heatwave has shown that many people died before getting to the hospitals.[2] Analysis of former heatwaves in England confirms the same pattern.[3] In France, compared with the years 2000–02, 14 800 excess deaths (+60%) were observed from August 1 to August 20. Deaths directly related to heat, heatstroke, hyperthermia and dehydration increased massively (+3306 deaths), as well as undefined morbid states (+1741), cardiovascular (+3004), respiratory diseases (+1365) and nervous system diseases (+1001). The highest tribute was paid by the elderly people, age of above 75 years (+82%), but the excess mortality was observed from 35 years old.[4] In-depth analysis of the hospital admissions is not available. In 2006, France experienced the first major heatwave since the implementation of its heat-prevention plan. About 2065 excess deaths occurred between July 11 and July 28. Following the hypothesis that heat-related mortality had not changed since 2003, 6452 excess deaths were predicted from the observed temperatures.[5] In the same period, no increase of the total emergency admissions of 49 hospitals was observed. Only admissions of people above 75 years of old for heat-related pathologies (hyperthermia, dehydratation, fainting and hyponatraemia) significantly increased.[6] The mortality lower than expected can be partially explained by a decrease in the population's vulnerability and by the efficiency of the prevention plan.[5] Although more feedback would be necessary, it seems that slowly the people are shifting to a better reaction towards acute heat. Can we conclude that the prevention of the short-term mortality is fulfilling its role and that the next challenge for European countries will be the identification of preventable heat-related morbidity? Indeed, a better understanding of the morbidity during heatwaves is needed. Clues may come from United States or Australia. In these countries, recent heatwaves were never as deadly as in Europe in 2003

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