Increased risk of emergency hospital admissions for children with renal diseases during heatwaves in Brisbane, Australia

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Background: **Heatwaves have a significant impact on population health including both morbidity and mortality. In this study we examined the association between heatwaves and emergency hospital admissions (EHAs) for renal diseases in children (aged 0-14 years) in Brisbane, Australia.**

Methods: **Daily data on EHAs for renal diseases in children and exposure to temperature and air pollution were obtained for Brisbane city from January 1, 1996 to December 31, 2005. A time-stratified case-crossover design was used to compare the risks for renal diseases between heatwave and non-heatwave periods.**

Results: **There were 1565 EHAs for renal diseases in children during the study period. Heatwaves exhibited a significant impact on EHAs for renal diseases in children after adjusting for confounding factors (odds ratio: 3.6; 95% confidence interval: 1.4-9.5). The risk estimates differed with lags and the use of different heatwave definitions.**

Conclusions: **There was a significant increase in EHAs for renal diseases in children during heatwaves in Brisbane, a subtropical city where people are well accustomed to warm weather. This finding may have significant implications for pediatric renal care, particularly in subtropical and tropical regions.**

World J Pediatr 2014;10(4):330-335

Key words: **climate change; environmental health; hot temperature; renal diseases**

Introduction

Heatwaves, which are likely to become more common and intense in the future as climate change continues,[1] can cause significant health consequences such as increased mortality and morbidity, particularly among the elderly with chronic illnesses and of low social class.[2-7] Exposure to extreme hot weather can cause 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 and compromise the function of the renal system.[3,8] Several studies[3,4,8-13] have reported increases in mortality and hospital admissions for renal dysfunction among the elderly during periods of high ambient temperatures. Most patients affected by hyperthermia experienced renal failure shortly after admissions, and severe renal diseases were amongst the prominent causes of excess mortality among the elderly.[12,13] Although it is suggested that climate change may affect children's health and put them in jeopardy,[14-18] there is relatively little empirical research into possible impact of climate change on children's health. To date, there is no specific report about the effect of heatwaves on renal diseases in children.

The Brisbane heatwave study started in 2009. Our preliminary results show that the definitions of heatwave used in previous studies may be not suitable for tropical/subtropical regions such as Brisbane and heatwaves seem to have a significant impact on excess deaths and hospital admissions in Brisbane even though people are well accustomed to warm weather.[5,6,19] Our data also show that a small change in the heatwave definition can produce an apparent difference in risk estimates.[5] The present study investigated the impacts of heatwaves on emergency hospital admissions (EHAs) for renal diseases in children in Brisbane, using a case-crossover design.

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doi: 10.1007/s12519-014-0469-x

Methods

Study population

Brisbane is the capital city of the state of Queensland. It is located in the south-east corner of the state (27º29'S, 153º8'E), and has a sub-tropical climate. It is Australia's third largest city (after Sydney and Melbourne), covering an urban area of 1326.8 km^2 with a population of 991 260 on June 30, 2006 (the year for the latest census with available data). The target population in this study included 175 625 children (aged 0-14 years) in Brisbane (18% of the total population).[20]

Data collection

Daily climate data including maximum temperature (Tmax) and relative humidity for the period of January 1, 1996 to December 31, 2005 in Brisbane were obtained from the Australian Bureau of Meteorology. Daily air pollution data on airborne particulate matter with diameter less than 10 micrometers (PM_{10}), nitrogen dioxide (NO_2) and Ozone (O_3) for the same period were provided by the Queensland Department of Environment and Resources Management (formally Queensland Environmental Protection Agency). The air pollution data were extracted from all available monitoring stations in Brisbane and averaged for each day. When data were missing for a particular monitoring station on a given day, the observations recorded from the other monitoring stations were used to compute the daily average values.

Daily data on EHAs were provided by the Health Statistics Unit (formerly Health Information Centre) at Queensland Health. The hospital dataset we acquired covers usual residents of Brisbane Local Government Area. The data included counts of admissions by date, principal diagnosis, age groups, and the number of admitted patient episodes of care. In this study, renal diseases were categorized according to the International Classification of Diseases (ICD) - revision 9 (ICD 9, 580-599) up to June 1999 and revision 10 (ICD 10, N00-N39) after that.

Statistical analysis

In a previous study we assessed heat-related health outcomes using multiple heatwave definitions (HDW).[5] Based on those results, we defined a heatwave in Brisbane as a daily maximum temperature of at least 37°C (top 0.5%) for two or more consecutive days (i.e., HWD 1). Case-crossover analyses were performed to assess the relationship between heatwaves and children's renal diseases in which each child serves as his or her own control. We considered exposure to heatwave as an independent variable and EHAs for renal diseases as a dependent variable. Our hypothesis was that the likelihood of the EHAs for renal diseases in children would increase during heatwave periods. Delayed effects of heatwaves on children's renal diseases of up to two days between exposure and admission were also explored as previous research suggests that heat effects are usually acute and short-term.[19] Conditional logistic regression model was used to assess the impact of heatwave on children's renal

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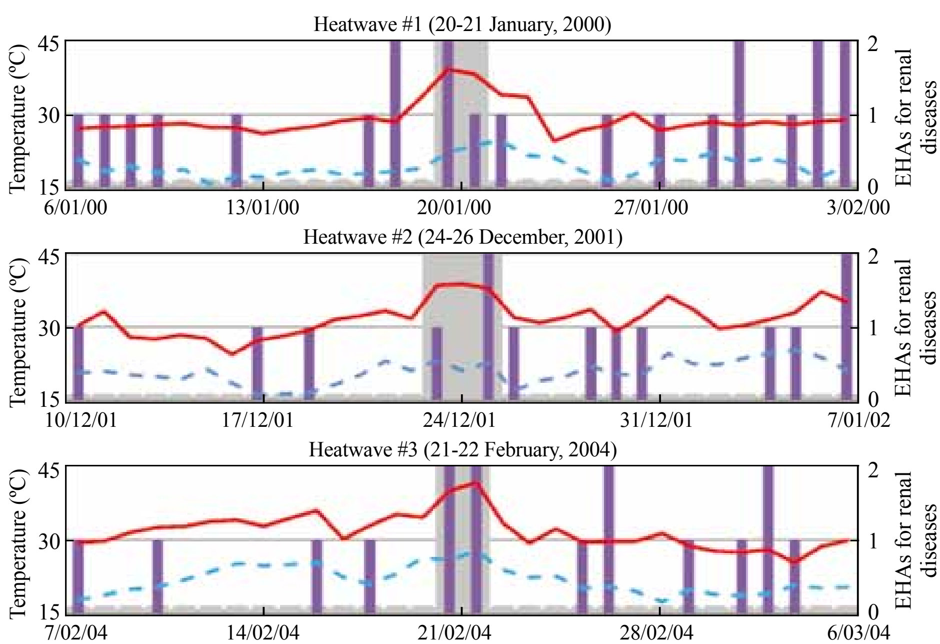

Fig. Heatwaves and daily EHAs for renal diseases in children in Brisbane, Australia, 1996-2005 (the solid lines are maximum temperature; the dotted lines are minimum temperature; the bars are EHAs for renal diseases and the shaded areas are heatwaves). A heatwave was defined as a daily maximum temperature of at least 37°C (top 0.5%) for two or more consecutive days. EHAs: emergency hospital admissions.

Table 1. Emergency hospital admissions for children (aged 0-14 years) with renal diseases in Brisbane, 1996-2005

Diseases	ICD 9/10	Episodes
Acute glomerulonephritis	580	14
Acute kidney failure	584	2
Acute nephritic syndrome	N00	17
Acute renal failure	N17	7
Acute tubulo-interstitial nephritis	N10	33
Calculus of kidney and ureter	592	3
Calculus of kidney and ureter	N20	3
Chronic glomerulonephritis	582	1
Chronic kidney disease	N18	11
Chronic kidney disease	585	13
Chronic tubulo-interstitial nephritis	N11	2
Cystitis	595	1
Cystitis	N30	5
Hydronephrosis	591	4
Infections of kidney	590	47
Nephritis and nephropathy not specified as acute or chronic	583	4
Nephrotic syndrome	581	16
Nephrotic syndrome	N04	23
Neuromuscular dysfunction of bladder, not elsewhere classified	N31	1
Obstructive and reflux uropathy	N13	10
Other disorders of bladder	596	2
Other disorders of bladder	N32	2
Other disorders of kidney and ureter	593	27
Other disorders of kidney and ureter, not elsewhere classified	N28	3
Other disorders of urinary system	N39	909
Other renal tubulo-interstitial diseases	N15	1
Recurrent and persistent hematuria	N02	2
Tubulo-interstitial nephritis, not specified as acute or chronic	N12	65
Unspecified kidney failure	N19	1
Unspecified nephritic syndrome	N05	7
Unspecified renal colic	N23	7
Urethral stricture	N35	1
Urethritis and urethral syndrome	N34	1

diseases after adjustment for confounding factors. The case-crossover approach is useful because it controls for time invariant variables by design.[21,22] In this study, we used the time-stratified case-crossover design with a stratum length of 45 days, and matched control days to case days using day of the week (the stratum length of 45 days gives 5 control days per case day). We adjusted for humidity and air pollutants (PM_{10}, NO_2 and O_3). In this analysis we defined same-day exposure as lag 0 and examined the effects of exposure up to 2 days before the admission (little effects were observed after a lag of 2 days; data not shown), as well as cumulative effects of lags 0-2. All case-crossover analyses were conducted using the SAS statistical software, version 9.1.[23] The odds ratios were calculated using the conditional logistic regression model with the PHREG procedure.

Results

Table 1 presents all EHAs for children's renal diseases by principle diagnosis codes (3 digits) and episodes. There were totally 1565 renal EHAs among children (aged 0-14 years) during the study period in Brisbane.

Three heatwaves were identified using HWD 1 during the study period (i.e., January 20 to 21, 2000; December 24 to 26, 2001; and February 21 to 22, 2004). All these heatwaves were short (2 to 3 days). The hottest day of the heatwave was February 22, 2004, with a maximum temperature of 41.5°C. Daily EHAs for renal diseases in children and temperatures (maximum and minimum) in Brisbane during the heatwaves (including the two weeks before and after each heatwave) are shown in Fig. It was shown that temperature is positively associated with daily EHAs for renal diseases, particularly tubulo-interstitial nephritis, not specified as acute or chronic (N12) and other disorders of the urinary system (N39).

Daily weather, air pollutants and EHAs for renal diseases in children (aged 0-14 years) using HWD 1 are shown in Table 2. The daily mean maximum temperature in heatwave period (12.8°C) was higher than in the study period. The average levels of daily 24-hour PM_{10}, maximum 1-hour NO_2 and O_3 were lower than the standard of the National Environment Protection Measure for ambient quality in Australia (50 μg/m^3, 0.12 ppb and 0.10 ppb, respectively). Compared with the whole study period, the mean number of EHAs for renal diseases increased remarkably during heatwaves.

The estimated odds ratios (ORs) of emergency hospital admissions for renal diseases in children using HWD 1 during heatwave versus non-heatwave days are shown in Table 3. There was a significant increase in

Table 2. Summary of daily weather, air pollutants and EHAs for renal disease among children in Brisbane, 1996-2005

Variables	Whole study period				Heatwave periods*			
	Mean	SD†	5%	95%	Mean	SD	5%	95%
Tmax (ºC)	26.3	3.9	20.2	32.7	39.1	1.3	37.9	41.5
Humidity (%)	71.1	10.3	52.3	86.8	60.3	6.5	51.1	67.4
PM_{10} (μg/m^3)	17.7	7.6	9.1	29.7	27.2	5.5	20.5	36.1
NO_2 (ppb)	18.0	6.7	8.7	30.3	18.4	4.2	13.7	26.8
O_3 (ppb)	31.8	9.8	18.7	50.2	49.8	8.8	40.8	67.8
Renal disease EHAs	0.4	0.7	0	2	1.4	0.8	0	2

*: the top 0.5% (37ºC) of daily maximum temperature for two or more consecutive days. †: standard deviation. EHAs: emergency hospital admissions; Tmax: maximum temperature.

Table 3. Odds ratios of emergency hospital admissions for renal disease in children during heatwaves (a daily maximum temperature of at least 37°C for two or more consecutive days) in Brisbane, 1996-2005

Model	OR (95% CI)	
	Unadjusted	Adjusted*
Lag 0	**3.13 [1.42-6.89]**	**2.94 [1.32-6.53]**
Lag 1	**3.73 [1.42-9.81]**	**3.59 [1.35-9.50]**
Lag 2	1.26 [0.42-3.71]	1.22 [0.41-3.60]
Lags 0-2	**2.16 [1.10-4.22]**	**2.08 [1.05-4.09]**

*: adjusted for humidity, PM_{10}, NO_2 and O_3.

EHAs for renal diseases during heatwaves after adjusting for confounders (including humidity, PM_{10}, NO_2 and O_3). The OR for admission on the day of exposure was 2.9 (95% CI: 1.3-6.5). The highest risk estimates were observed at lag 1 (OR: 3.6; 95% CI: 1.4-9.5), and the cumulative effect of lags 0-2 was also observed.

Discussion

This study examined the effects of heatwaves on children's health which is particularly concerning because children are thought to be more vulnerable to the impact of climate change than adults. To our knowledge, this is the first study to specifically investigate the association between heatwaves and emergency hospital admissions for renal diseases among children. Our results show a consistent and increased risk of EHAs for children's renal diseases during heatwaves in Brisbane, where the people are well accustomed to hot summer weather. The results of this study show that exposure to heat at the same day, lag 1, and 3 days' cumulative exposure significantly increased the risk of EHAs for children's renal diseases. The strongest heatwave effects appeared at lag 1. We analyzed the sensitivity using the same methods on some less stringent heatwave definitions [i.e., HWD 2: top 1% (35ºC) of daily maximum temperature for two or more consecutive days, and HWD 3: top 2.5% (33.6ºC) of daily maximum temperature for three or more consecutive days]. The total heatwave days for HWDs 2 and 3 were 20 and 30 days, respectively (1996 and 2005). However, the risk estimates were alleviated when the less stringent heatwave definitions (HWDs 2 and 3) were used (results not shown).

Previous studies have focused on heat-related renal diseases in adults or the whole population. For example, Hansen et al[8] reported that there was a 10% increase in hospital admissions for all renal disease during heatwave periods in Adelaide, Australia (located at 34°52'S, 138°30'E), compared with non-heat wave periods in 2004. Age-specific analysis showed increases in renal hospital admissions across different age and sex groups, especially for elderly women (rate ratios for women aged 85+ years: 1.2; 95% CI: 1.0-1.5), but the age-specific analysis in that study did not include children. A study of emergency hospital admissions in London also found an increase in renal diseases for all ages associated with hot weather.[4] A few studies[10,11,24] have reported increased hospital admissions due to acute renal failure during heatwaves. These studies provide supportive evidence of heat-related renal impairment.[25-28]

The EHAs for renal diseases in children accounted for 7.1% of all EHAs for renal diseases in Brisbane during the study period. We postulate that increased renal EHAs among children during heatwaves might be truly causal rather than an artefact because accumulating evidence suggests that exposure to high temperatures is associated with increased odds of hospitalization for renal diseases.[10,29] In our previous study,[19] we also found there was a significant increase in EHAs for total renal disease during heatwaves particularly in those aged 64-75 years. However, none of the previous studies has focused on children. The biologic mechanism underlying the relation of heat and renal disease is unclear. Previous studies have demonstrated an association between exposure to heat and increased incidence of renal calculi.[26,30] Other studies have found that renal failure as a consequence of heatstroke may be caused by either dehydration or direct kidney damage from rhabdomyolysis.[24,31]

The present study has a number of strengths. As the first study to examine the effects of heatwaves on children's renal diseases, the findings of this study may have significant implications for pediatric renal care if our results are confirmed by further studies. The data used in this study were comprehensive and of good quality, covering a decade with no missing values. Finally, we were able to adjust for the possible confounding effects of air pollution and humidity when we assessed the impact of heatwaves on EHAs for renal diseases in children.

This study also has several limitations. It focused on only one city and the results of this study need to be interpreted cautiously. However, the finding of a consistently increased pattern of EHAs for renal diseases in children during heatwaves may inspire further research in other locations. Although the study covered a 10-year period, there was only a small number of heatwaves identified, indicating that the sample size was small in the case-crossover analysis even with the less stringent HWDs. Additionally, we are unable to determine the prevalence of children with preexisting renal diseases or other co-morbid conditions who may be at a higher risk of EHAs for heatwave related illness when compared with healthy children. There was also possibility of bias due to mis-classified ICD codes. Finally, only a broad category of renal diseases was used in this study. We

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were unable to categorise renal diseases in more details because there was only a small proportion of excess cases of renal diseases during heatwaves.

In conclusion, a significant increase in emergency hospital admissions for renal diseases in children was observed during heatwaves in Brisbane, a subtropical city where people are well accustomed to warm weather. The findings from this study are expected to have implications for improving pediatric renal care and better understanding heat-related effects on children's health, so that appropriate intervention strategies can be developed to prevent and mitigate the public health impact of heatwaves. Children are one of the most vulnerable groups to climate change, and more research is warranted to assess the consequences of climate change from a children's health perspective.

Acknowledgements

We thank the Queensland Health, Environmental Protection Agency, Office of Economic and Statistical Research of the Queensland Treasury, and Australia Bureau of Meteorology for providing the relevant data.

Funding: This study was partly funded by Australian Research Council (DP0559655), Queensland Departments of Environment and Resources, Community Safety, Queensland Health, and Environmental Protection Agency. TSL was supported by an NHMRC research fellowship (#553043).

Ethical approval: An ethical approval was granted by the Human Research Ethical Committee, Queensland University of Technology.

Competing interest: None.

Contributors: Tong S was responsible for the conceptualization and conduct of the whole study. He has full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study design and data acquisition: Tong S and Barnett AG. Analysis and interpretation of data: Wang XY, Barnett AG, Guo Y and Tong S. Drafting of the manuscript: Wang XY and Tong S. Critical revision of the manuscript for important intellectual content: Tong S, Barnett AG, Guo Y, Yu W and Shen X.

References

1 Anderson GB, Bell ML. Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. communities. Environ Health Perspect 2011;119:210-218.
2 Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: Synthesis Report. IPCC, Geneva, Switzerland, 2007.
3 Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. Excess hospital admissions during the July 1995 heat wave in Chicago. Am J Prev Med 1999;16:269-277.
4 Kovats RS, Hajat S, Wilkinson P. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occup Environ Med 2004;61:893-898.
5 Tong S, Wang XY, Barnett AG. Assessment of heat-related health impacts in Brisbane, Australia: comparison of different heatwave definitions. PLoS One 2010;5:e12155.
6 Tong S, Ren C, Becker N. Excess deaths during the 2004 heatwave in Brisbane, Australia. Int J Biometeorol 2010;54:393-400.
7 Huang W, Kan H, Kovats S. The impact of the 2003 heat wave on mortality in Shanghai, China. Sci Total Environ 2010;408:2418-2420.
8 Hansen AL, Bi P, Ryan P, Nitschke M, Pisaniello D, Tucker G. The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. Int J Epidemiol 2008;37:1359-1365.
9 Kovats RS, Kristie LE. Heatwaves and public health in Europe. Eur J Public Health 2006;16:592-599.
10 Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, et al. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect 2009;117:61-67.
11 Mastrangelo G, Hajat S, Fadda E, Buja A, Fedeli U, Spolaore P. Contrasting patterns of hospital admissions and mortality during heat waves: Are deaths from circulatory disease a real excess or an artifact? Med Hypotheses 2006;66:1025-1028.
12 Fouillet A, Rey G, Laurent F, Pavillon G, Bellec S, Guihenneuc-Jouyaux C, et al. Excess mortality related to the August 2003 heat wave in France. Int Arch Occup Environ Health 2006;80:16-24.
13 Barbieri A, Pinna C, Fruggeri L, Biagioni E, Campagna A. Heat Wave in Italy and Hyperthermia Syndrome. South Med J 2006;99:829-831.
14 Voelker R. Climate change puts children in jeopardy. JAMA 2009;301:2197-2199.
15 Ebi KL, Paulson JA. Climate change and child health in the United States. Curr Probl Pediatr Adolesc Health Care 2010;40:2-18.
16 Ebi KL, Paulson JA. Climate Change and Children. Pediatr Clin North Am 2007;54:213-226.
17 Shea KM; American Academy of Pediatrics Committee on Environmental Health. Global climate change and children's health. Pediatrics 2007;120:e1359-1367.
18 Zemek R, Szyszkowicz M, Rowe BH. Air Pollution and Emergency Department Visits for Otitis Media: A Case-Crossover Study in Edmonton, Canada. Environ Health Perspect 2010;118:1631-1636.
19 Wang XY, Barnett AG, Yu W, FitzGerald G, Tippett V, Aitken P, et al. The impact of heatwaves on mortality and emergency hospital admissions from non-external causes in Brisbane, Australia. Occup Environ Med 2012;69:163-169.
20 Queensland Treasury. Population and Housing Profile. www.oesr.qld.gov.au/queensland-by-theme/demography/population-characteristics/profiles/pop-housing-profile-lga/pophousing-profile-brisbane.pdf. (accessed June 16, 2012).
21 Barnett AG, Dobson AJ. Analysing Seasonal Health Data. Springer, New York: 2010.
22 Janes H, Sheppard L, Lumley T. Case-crossover analyses of air pollution exposure data: referent selection strategies and their implications for bias. Epidemiology 2005;16:717-726.
23 SAS. Institute Inc. 2003. SAS Statistical Software, version 9.1. Cary, NC: SAS Institute, Inc.
24 Semenza JC. Acute renal failure during heat waves. Am J Prev

Med 1999;17:97.
25 Sheffield PE, Landrigan PJ. Global climate change and children's health: threats and strategies for prevention. Environ Health Perspect 2011;119:291-298.
26 Brikowski TH, Lotan Y, Pearle MS. Climate-related increase in the prevalence of urolithiasis in the United States. Proc Natl Acad Sci U S A 2008;105:9841-9846.
27 Fakheri RJ, Goldfarb DS. Association of nephrolithiasis prevalence rates with ambient temperature in the United States: a re-analysis. Kidney Int 2009;76:798.
28 Mandeville JA, Nelson CP. Pediatric urolithiasis. Curr Opin Urol 2009;19:419-423.
29 Fletcher BA, Lin S, Fitzgerald EF, Hwang SA. Association of summer temperatures with hospital admissions for renal diseases in new york state: a case-crossover study. Am J Epidemiol 2012;175:907-916.
30 Lo SS, Johnston R, Al Sameraaii A, Metcalf PA, Rice ML, Masters JG. Seasonal variation in the acute presentation of urinary calculi over 8 years in Auckland, New Zealand. BJU Int 2010;106:96-101.
31 Bouchama A, Knochel JP. Heat stroke. N Engl J Med 2002;346:1978-1988.

Received October 22, 2012
Accepted after revision March 29, 2013