Medical diagnoses of heat wave-related hospital admissions in older adults

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ABSTRACT

Heat waves have been associated with adverse human health effects, including higher rates of all-cause and cardiovascular mortality, and these health effects may be exacerbated under continued climate change. However, specific causes of hospitalizations associated with heat waves have not been characterized on a national scale. We systematically estimated the risks of cause-specific hospitalizations during heat waves in a national cohort of 23.7 million Medicare enrollees residing in 1943 U.S. counties during 1999–2010. Heat waves were defined as ≥2 consecutive days exceeding the county's 99th percentile of daily temperatures, and were matched to non-heat wave periods by county and week. We considered 50 outcomes from broad disease groups previously associated with heat wave-related hospitalizations, and estimated cause-specific relative risks (RRs) of hospital admissions on heat wave days. We identified 11 diagnoses with a higher admission risk on heat wave days, with heat stroke and sunstroke having the highest risk (RR = 22.5, [95% CI 14.9–34.2]). Other diseases with elevated risks included fluid and electrolyte disorders [(Hyperosmolality RR = 1.4, [95% CI 1.1–1.3]; Hypoosmolaltiy RR = 1.2, [95% CI 1.1–1.3])] and acute kidney failure (RR = 1.1, [95% CI 1.1–1.2]). These risks tended to be higher under more severe heat wave events. In addition, risks were higher among adults in the oldest (≥85) category (reference: 65–74) for volume depletion and heat exhaustion. Several causes of hospitalization identified are preventable, and public health interventions, including early warning systems and plans targeting risk factors for these illnesses, could reduce adverse effects of heat in the present and under climate change.

1. Introduction

Heat waves have been associated with adverse human health effects, including higher rates of all-cause cardiovascular mortality and emergency hospitalizations, as well as respiratory and renal failure (Bobb et al., 2014a; Bobb et al., 2014b; Thornbrugh et al., 2007; Robine et al., 2008). In the United States, extreme heat caused more deaths than all other extreme weather events combined over the past 15 years (Thornbrugh et al., 2007; Dematte et al., 1998; Robine et al., 2008). With continued climate change, heat waves and extreme weather events are expected to become more frequent, intense, and longer lasting (Bobb et al., 2014a; Meehl & Tebaldi, 2004; Gronlund et al., 2014).

Exposure to extreme heat can affect many organ systems, which may lead to renal failure, neurological impairments, and cardiovascular failure (Leon & Helwig, 2010). Although heat has a range of physiological effects, epidemiological studies of health effects have generally limited their focus to all-cause, respiratory, or cardiovascular disease categories, as well as common diseases like heat stroke and dehydration (Bobb et al., 2014a; Turner et al., 2012). In addition, many studies considered just a single heat wave event, in a particular city or region, rather than prospectively study a large cohort across a broad geographical area (Dematte et al., 1998).

One recent study, which addressed many of the limitations of prior analyses, investigated the full spectrum of diseases that were associated with hospital admissions during extreme heat events in a large population of Medicare enrollees in the United States during 1999–2010 (Bobb et al., 2014a). This study classified approximately 15,000 ICD-9 codes into a more manageable set of 283 clinically meaningful disease groups, and identified 6 disease categories with statistically significant risks of hospital admissions during heat waves (fluid and electrolyte disorders, renal failure, urinary tract infections, septicemia, congestive heart failure (CHF), and other injuries and conditions due to external causes). However, the specific diagnoses that drive the association between these disease groups and heat wave-related hospital admissions have not been characterized. In particular, these 6 disease categories

comprise 186 distinct diagnosis codes, reflecting heterogeneous biological pathways.

To address this gap, we expanded on this prior study to test the association between heat wave exposure and hospital admissions for each of the medical diagnoses within these disease groups. We further investigated whether the risks increased when the heat wave was more intense (higher temperature) and for a longer duration (additional consecutive days). Finally, we examined whether individuals in older age groups had higher hospitalization risks during heat waves.

2. Methods

We used a linked national database of daily data on hospital admissions and weather for a population of 23.7 million fee-for-service Medicare enrollees (roughly 85% of all Medicare enrollees) residing in 1943 counties in the United States, aged 65 years or older, followed during the period 1999–2010. A complete description of the data has been detailed previously (Bobb et al., 2014a). Briefly, the data comprise parallel time series of daily temperature data from National Centers for Environmental Information (previously National Climatic Data Center), counts of the daily number of cause-specific hospital admissions, defined using the principal discharge diagnosis code [*International Classification of Diseases, Ninth Revision (ICD-9-CM)*], and counts of the daily number of Medicare enrollees at risk of hospitalization (denominator).

We defined a heat wave event as a period of ≥ 2 or ≥ 4 consecutive days with average daily temperatures exceeding the 97th, 98th, or 99th percentile for that county (Bobb et al., 2014a; Anderson & Bell, 2009) (the 2-day, 99th percentile definition was used for the primary analysis). A heat wave day was defined as the second or later day, or fourth or later day (depending on the definition used) during that heat wave period. For each of the 1943 counties, we identified all of the heat wave events during the study period. Heat wave days were matched to non-heat wave days by county and by week: for each heat wave day, we first identified non-heat wave days in that county that were within 3 days of the heat wave day (but in other years) (Bobb et al., 2014a). We then randomly selected one of these candidates as the matched non-heat wave day to achieve 1:1 matching.

To evaluate the cause-specific health risks associated with heat wave exposure, we considered each ICD-9-CM diagnosis code within the 6 broad disease categories (defined using the Clinical Classifications Software (CCS) algorithm of the Agency for Healthcare Research Quality (HCUP CCS, 2015)) previously associated with heat waves (Bobb et al., 2014a). To ensure a sufficient number of events for model fitting, we excluded diagnoses with fewer than 100 total admissions on both heat wave days and non-heat wave days, leaving 50 diagnoses for analysis (Supplemental Table S1). For each diagnosis, we fit log-linear mixed-effect regression models to the matched dataset of heat wave days and non-heat wave days, regressing the daily number of admissions on the heat wave day indicator variable. The model also included an offset for the number of individuals at risk and a county-specific random intercept to account for correlation of daily hospitalizations within a county. We adjusted for possible confounding by temporal trends not addressed through matching by including day of the week and calendar year, both as categorical variables (Bobb et al., 2014a). From the model, we estimated the diagnosis-specific RR of admission comparing heat wave day to a matched non-heat wave day.

3. Results

All 1943 counties had at least one heat wave (under the primary definition), with the median (IQR) number of heat wave days over the study period of 17 (13–20; Table S2). Of the 50 diagnoses considered, 12 had statistically significant RRs under the primary heat wave definition (Fig. 1; Table S3). Of these, 11 had a higher risk of hospitalization during heat wave days as compared to non-heat wave days, and 1 had a lower risk. Seven of the 12 diagnoses with significant risks came

from the fluid and electrolytes disorders and the other injuries and conditions due to external causes disease categories. Estimates ranged from an RR of 22.5 (95% CI, 14.9–34.2) for heat stroke and sunstroke (i.e., a 22.5 times higher risk) to an RR of 1.1 (95% CI, 1.0–1.1) for unspecified septicemias.

To evaluate the potential gains of studying individual medical diagnoses, we also compared the diagnosis-specific estimates with the original risk estimates for the broader disease groups (Fig. 1). We found that for all of the disease groups, the individual diagnosis-specific risk estimates were larger (i.e., further from the null) than for the overall category. Notably, as compared to the disease category heat stroke and other external causes, which had a RR of 2.5, the medical diagnoses within that group ranged from 8.0 for heat exhaustion (anhydrotic) to 22.5 for heat stroke and sunstroke.

Among diagnoses where we found significant RRs under the primary heat wave definition, we found higher RRs when the heat wave was more intense (a higher percentile) for most diagnoses (Fig. 2; Table S4); the risks also tended to be higher under the 4-day (versus 2-day) definition, although this trend was less pronounced. Formally, we tested whether the RR under the most severe (≥ 4 days, > 99th percentile) heat wave definition differed from the RR under the least severe (2 days, > 97th percentile), and found a statistically significant difference for six of the diagnoses (Fig. 2).

We further investigated potential effect modification by age, finding evidence of a higher risk of heat wave adverse effects in the oldest (≥ 85) versus youngest (65–74) group for volume depletion and heat exhaustion (Table S5).

4. Discussion

This study provides a detailed characterization of the range of medical diagnoses that occur during heat waves among older adults. We found evidence of a higher rate of hospital admissions for 11 medical diagnoses during heat wave days, including 3 heat-related illnesses, 4 fluid and electrolyte disorders, 2 diagnoses for septicemia, acute kidney failure, and urinary tract infection; we also found 1 diagnosis (CHF) that had a lower risk of hospital admissions during heat waves. Results were robust across alternative definitions of a heat wave that considered different intensities and durations of heat exposure.

Our findings reflect knowledge of the physiological effects of extreme heat, which can cause multiorgan dysfunction (Leon & Helwig, 2010). Not surprising, we found the highest risk for heat stroke, with an RR of 22.5 (95% CI, 14.9–34.2). Heat stroke has been shown to have high emergency department case fatality rates (Hess et al., 2014), when core body temperatures raise and neurological dysfunction may occur (Knochel & Reed, 1994). Mild to moderate heat illness is reversible with prompt treatment; however, its rapid development can be fatal if left untreated. Additionally, hyperthermia associated with heat stroke can lead to the failure of the body's temperature control and regulation system, making the body more susceptible to other bacteria and infection, and possibly correlate with the change in incidence of infections, such as septicemia or urinary tract infection. Another major factor that can cause heat-related illness is dehydration, which can reduce the body's thermoregulation ability through sweating, leading to increases in internal body temperature. Kidney failure has also been associated with several factors that could induce hospital admissions during heat waves, including direct thermal injury and prerenal acute injury correlated with dehydration (Bobb et al., 2014a; Dematte et al., 1998). Lastly, the reasoning behind the potential protective effect of CHF is not solidified. One possible explanation is that large losses of fluid could potentially reduce the risk of volume overload (Bobb et al., 2014a), though this finding could also be due to chance and should be interpreted cautiously. Previous studies have found an increased risk of mortality due to cardiovascular diseases such as CHF (Bobb et al., 2014a; Anderson & Bell, 2009; Basu, 2009), although another meta-analysis did not find a statistically significant association (Turner et al.,