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Clinical Study

Elevated relative risk of aneurysmal subarachnoid hemorrhage with colder weather in the mid-Atlantic region

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ABSTRACT

We have previously reported an increase of 0.6% in the relative risk of aneurysmal subarachnoid hemorrhage (aSAH) in response to every 1°F decrease in the maximum daily temperature (Tmax) in colder seasons from patients presenting to our regional tertiary care center. We hypothesized that this relationship would also be observed in the warmer summer months with ambient temperatures greater than 70°F. From prospectively collected incidence data for aSAH patients, we investigated absolute Tmax, average daily temperatures, intraday temperature ranges, and the variation of daily Tmax relative to 70°F to assess associations with aSAH incidence for patients admitted to our institution between 1991 and 2009 during the hottest months and days on which Tmax > 70°F. For all days treated as a group, the mean Tmax (± standard deviation) was lower when aSAH occurred than when it did not (64.4 ± 18.2°F *versus* 65.8 ± 18.3°F; $p = 0.016$). During summer months, the odds ratio (OR) of aSAH incidence increased with lower mean Tmax (OR 1.019; 95% confidence interval 1.001–1.037; $p = 0.043$). The proportion of days with aSAH admissions was lower on hotter days than the proportion of days with no aSAH (96% *versus* 98%; $p = 0.006$). aSAH were more likely to occur during the summer and on days with a temperature fluctuation less than 10°F (8% *versus* 4%; $p = 0.002$). During the hottest months of the year in the mid-Atlantic region, colder maximum daily temperatures, a smaller heat burden above 70°F, and smaller intraday temperature fluctuations are associated with increased aSAH admissions in a similar manner to colder months. These findings support the hypothesis that aSAH incidence is more likely with drops in temperature, even in the warmer months.

1. Introduction

Subarachnoid hemorrhage (SAH) is ranked fourth on the list of neurologic diseases which caused the highest years of potential life lost as a result of in-hospital death in the USA between 1988 and 2011 [1]. Despite major advances in diagnosis and treatment, SAH continues to have very high rates of mortality (25.5%) [1] and disability. The strongest independent risk factors for aneurysmal subarachnoid hemorrhage (aSAH) are hypertension and active smoking [2–4]. Controversy exists regarding climate variations and aSAH incidence. While some authors have found a strong association of aSAH with extrinsic factors such as season [5–11], atmospheric pressure [12–15] and humidity [16,17], these relationships have been inconsistent across cohorts and climates [18–20].

We recently reported a relationship between increasing relative risk of aSAH and drops in temperature in >1000 events of aSAH presenting to our referral center. Our study was unique in two ways. We focused primarily on the change in temperature in times of seasonal temperature variability with large shifts from relatively warm temperatures to colder ambient temperatures, and we determined how this temperature shift to colder temperatures affected the relative risk of ruptured aneurysms presenting to our tertiary medical center as opposed to population-based individual attributable risk [21]. Colder temperatures affect the incidence of cardiovascular and cerebrovascular-related events such as stroke and myocardial infarction, with an increasing incidence associated with colder temperatures [22–25]. We posit that two temperature-related events are associated with increased aSAH incidence: a drop in temperature from warmer to colder temperatures, and a general effect of colder temperatures on increased incidence. The goal of the present analysis was to investigate the effect of temperature change from hotter to colder in times when the

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ambient temperature was equal to or greater than the optimal human temperature of 70°F using data from our previously observed and reported cohort. For this study, we hypothesized that the likelihood of aSAH incidence presenting to our referral center would increase with temperature drops, intraday or over multiple days, even in summer months with warmer ambient background temperatures of greater than 70°F.

2. Methods

A prospectively collected database of patients with aSAH admitted to our institution between 1991 and 2009 was retrospectively analyzed as previously reported [21]. The supporting referral network encompasses a large portion of the mid-Atlantic region including the greater Baltimore metropolitan area, the state of Maryland, the state of Delaware, the District of Columbia, northern Virginia, and portions of southern Pennsylvania in the USA. According to the 2007 USA census, the populations of these regions are substantial with 5,828,289 people living in the state of Maryland, an estimated 8 million in the greater Baltimore–Washington DC corridor, and 907,135 in Delaware. In this study, most patients came from the greater Baltimore metropolitan area with a population of 2,668,056 people.

Weather data for Baltimore, Maryland, for the period of December 1990 to March 2009 was obtained from the USA National Weather Service and was synchronized with the dates of aSAH onset. The hospital admission day was used when the timing of hemorrhage was uncertain [21]. Historical data from the National Weather Service and daily weather data for Baltimore, Maryland, was linked to each date of aSAH incidence.

Weather data included daily maximum (Tmax) and minimum (Tmin) ambient temperatures (°F), daily maximum and minimum relative humidity measured as a percent, and daily atmospheric pressure measured in inches of mercury. The unit of measure was days and the outcome of interest was the presentation of a patient with a radiologically confirmed aSAH on a given day to the Johns Hopkins Neuroscience service.

2.1. Statistical analyses

Absolute Tmax, Tmin, intraday and interday temperature variation, temperature burden and variation from ideal temperature were analyzed by day, month, over the entire study period, and in groupings of hottest months. The days during the study period were dichotomized into those with incidents of aSAH and those without. Days were also categorized into those that had Tmax or Tmin values above 70°F, and those that did not. Dichotomous variables were compared using the chi-squared test or Fisher's exact test, where appropriate. The independent samples t-test (two-tailed) was used to analyze normally distributed continuous variables. Non-parametric tests (Mann–Whitney U test, Kruskal–Wallis test, Spearman's correlation coefficient) were used for variables with non-normal distributions. The level of significance was set at $p < 0.05$. Data were analyzed with SPSS software (version 20.0; IBM Corporation, Armonk, NY, USA) and are presented as the mean ± standard deviation, where appropriate.

3. Results

3.1. Patient characteristics

As reported previously, between January 1 1991 and March 31 2009, 1168 patients with acute aSAH were admitted to our institution and were included in the study [21]. The mean age was 51.9 ± 14.5 years and 852 (73%) of the patients were women. Regarding race, 59% of patients were Caucasian and 37% were African American (Table 1). The median admission Glasgow coma scale score was 14 (range: 3–15) and the median Hunt and Hess scale score was 2 (range: 1–5). Sixty six percent of patients (777) had one brain aneurysm, 25% (288) had two and 9% (103) had more than two. The most common location of the brain aneurysms was the anterior communicating artery, followed by the posterior communicating artery (Table 2).

3.2. Overall aSAH incidence

aSAH occurred on 17% of the 6711 days in the study period. The month with the highest aSAH rate was October with new hemorrhages occurring on 118 of 562 days (21%). This was followed by January with 109 of 593 days (18.4%). The lowest rates were observed in April and August (15.0%). The mean monthly incidence was 17.4% (Table 3; Fig. 1). The likelihood of aSAH incidences increased as the ratio of Tmax to 70°F fell below zero (colder temperatures) in most of the months (Fig. 2).

3.3. Daily temperature extremes and aSAH incidence

When all days were examined as a group, the mean Tmax was lower when aSAH occurred than when it did not (64.4 ± 18.2°F *versus* 65.8 ± 18.3°F; $p = 0.016$). Hemorrhage was also more likely to occur on cooler days. The proportion of days with aSAH episodes was higher when the maximum temperature was below 70°F (58% of days with aSAH *versus* 53% of days with no aSAH; odds ratio [OR] 1.185; 95% confidence interval [CI] 1.042–1.345; $p = 0.009$). The opposite was seen on days when Tmax equaled or exceeded 70°F (42% of days with aSAH *versus* 46% of days with no aSAH; OR 0.845; 95% CI 0.744–0.960; $p = 0.009$; Table 4).

Even in the hottest seasonal time periods, the risk of aSAH was higher on the coldest days. During the summer months, the OR of aSAH incidences increased with lower mean Tmax (OR 1.019; 95% CI 1.001–1.037; $p = 0.043$). The proportion of days with aSAH admissions was lower on hotter days than the proportion of days with no aSAH (96% *versus* 98%; $p = 0.006$).

Table 1
Aneurysmal subarachnoid hemorrhage patient characteristics (n = 1168)

Demographics	
Age, years	51.9 ± 14.5[a]
Sex, female	852 (73)
Race/ethnicity	
Caucasian	690 (59)
African-American	427 (37)
Hispanic	15 (1)
Other	28 (2)
Clinical SAH Characteristics	
Admission GCS	14 (3–15)[b]
Admission HH	2 (1–5)[b]
1	402 (34)
2	159 (14)
3	292 (25)
4	156 (13)
5	87 (7)
Hydrocephalus	530 (45)
Hematoma	235 (20)
Number of aneurysms in a single patient	
1	777 (66)
2	288 (25)
>2	103 (9)

Data are presented as n (%) unless otherwise specified.
GCS = Glasgow coma scale score, HH = Hunt and Hess scale score, SAH = subarachnoid hemorrhage.
[a] Mean ± standard deviation.
[b] Median (range).