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ORIGINAL ARTICLE

Effects of Barometric Pressure and Temperature on Acute Ischemic Stroke Hospitalization in Augusta, GA

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Abstract

Several studies worldwide have demonstrated significant relationships between meteorological parameters and stroke events. However, authors often reported discordant effects of both barometric pressure and air temperature on stroke occurrence. The present study investigated whether there was an association between weather parameters (barometric pressure and temperature) and ischemic stroke hospitalization. The aim of the study was to find out whether daily barometric pressure may be used as a prognostic variable to evaluate the workload change of a neurological intensive care unit. We conducted a retrospective review study in which we collected the independent (barometric pressure and temperature) and dependent variables (stroke hospitalization) every 24 h for the periods 10/1/2016–4/30/2017 at Augusta University Medical Center of Augusta, GA. We analyzed the data with zero-inflated Poisson model to assess the relationship between the barometric pressure, temperature, and daily stroke hospitalization. The results showed that there was a significantly correlation between daily barometric pressure variation and daily stroke hospitalization, especially on elder male patients (≥ 65). Stroke events were more likely to occur in the patients with risk factors than in those without risk factors when exposed to barometric pressure and temperature changes. Decreased barometric pressure and increased temperature were associated with increased daily stroke hospitalization. Furthermore, there was a potential delayed effect of increased stroke events after cold temperature exposure. Barometric pressure and temperature changes over the preceding 24 h are associated with daily stroke hospitalization. These findings may enhance our understanding of relationship between stroke and weather and maybe used in the development of public health strategies to minimize the weather-related stroke risk.

Keywords Barometric pressure · Temperature · Stroke · Hospitalization

Introduction

Stroke is the leading cause of serious long-term disability in the USA [1]. About 800,000 people experience a new or recurrent stroke and nearly 133,000 people die each year from stroke in the USA [1]. Barometric pressure is an atmospheric variable that affects the human organism. Changes in barometric pressure have diurnal and seasonal variations. Effect of barometric pressure on acute stroke occurrence is supported by biological and epidemiological evidences [2–9]. Many studies have evaluated the association between weather and stroke. However, authors often report discordant effects of both barometric pressure and air temperature on stroke occurrence. This may be due to differences in study design, study population, geographical area, and potential confounders. Some studies have reported lower barometric pressure and temperature were associated with increased stroke incidence [3, 4, 8–10] and others concluded the converse [2, 5–7]. Furthermore, the potential delayed effect of stroke events after temperature exposure and the interactive effect between barometric pressure and temperature have not been fully investigated.

Therefore, the present study investigated whether there was an association between weather parameters (barometric

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pressure and temperature) and ischemic stroke hospitalization based on daily variation in Augusta University Medical Center, Augusta, GA, USA. We also evaluated the relative risk (RR) of stroke hospitalization stratified by sex, age, and risk factor groups. The purpose of the study was to find out whether daily barometric pressure may be used as a prognostic variable to quantitatively estimate the expected increases in hospital admissions of ischemic stroke, thus evaluating the workload change of the neurological intensive care unit.

Methods

Study Population

The study population were the patients admitted to the intense care unit (ICU) of Augusta University Medical Center (Augusta, GA) with admission diagnosis of ischemic stroke (ICD code I63) between 10/1/2016 and 4/30/2017. Sample size was 240 inpatients in the ICU of Augusta University Medical Center of Augusta, GA. The flowchart of patient selection is documented in Fig. 1.

Study Procedure

This retrospective study was conducted at Augusta University Medical Center. Prior to data collection, the study was approved by the Augusta University's medical institutional review board on August 31st of 2017. For this type of study, informed consent was not required. Data were collected over 212 days, from October 1, 2016, to April 30, 2017, which was selected based on the seasonal variations of barometric pressure and temperature in the area of Augusta, GA (Fig. 2). No protected health information (PHI) was collected as data for this study. Daily stroke hospitalization was obtained from i2b2 and Electronic Medical Records (EMR). Barometric pressure and temperature were collected every 24 h from www.wunderground.com/us/ga/augusta. The investigators described changes of barometric pressure and temperature as mean value, variation within 24 h, and variation between 24 h.

Statistical Analysis

In order to assess the influence of barometric pressure and temperature on stroke hospitalization, the investigators used zero-inflated Poisson regression analysis to calculate *P* values. We used linear regression analysis to evaluate the association between barometric pressure and temperature. Monthly variations of barometric pressure and temperature were analyzed by non-parametric analyses (Kruskal-Wallis and Wilcoxon tests). We used JMP Pro 13 (USA) and SAS 8.4 (USA) for statistical analysis, and the statistical significant level was set at $P < 0.05$.

Results

Baseline Characteristics of Study Subjects

The baseline characteristics of the enrolled subjects are described in Table 1. Among the 240 stroke inpatients (63.37 ± 24.75 years old), there were 5 patients (2.1%) less than 18 years old (7.6 ± 6.1 years old), 109 patients (45.4%) less than 65 years old (51.8 ± 10.0 years old) and older than 18 years old (45.4%), and 126 patients (52.5%) equal or older than 65 years old (76.6 ± 8.40 years old). There were a total of 131 male patients (60.8 ± 17.1 years old) and 109 female patients (67.5 ± 17.0 years old) included in this study.

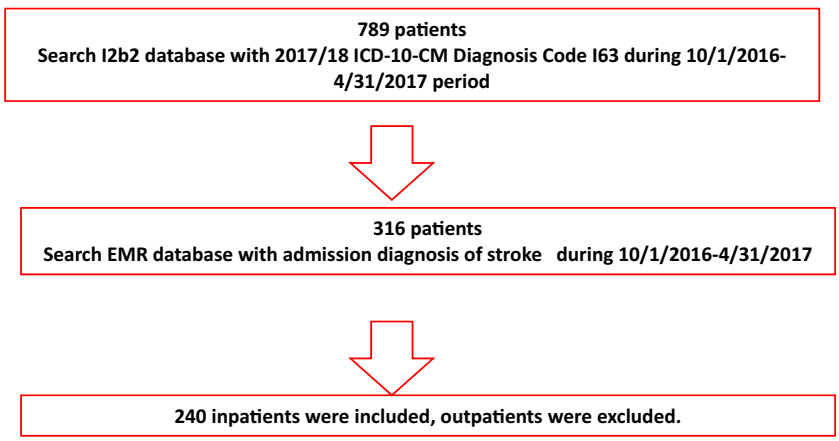

Fig. 1 Study population selection. Flow chart describing study subject selection. First, 789 patients were primarily included in i2b2 database which were screened with ICD-10-CM diagnosis code I63 during the period of 10/1/2016 to 4/31/2017. ICD-10-CM code I63 includes "occlusion and stenosis of cerebral and precerebral arteries, resulting in cerebral infarction" (http://www.icd10data.com/ICD10CM/Codes/I00-I99/I60-I69/I63-/I63). Second, 316 patients were selected basing on the admission diagnosis of stroke during the period of 10/1/2016 to 4/31/2017. Finally, there were total 240 inpatients included in the study and 76 outpatients excluded out

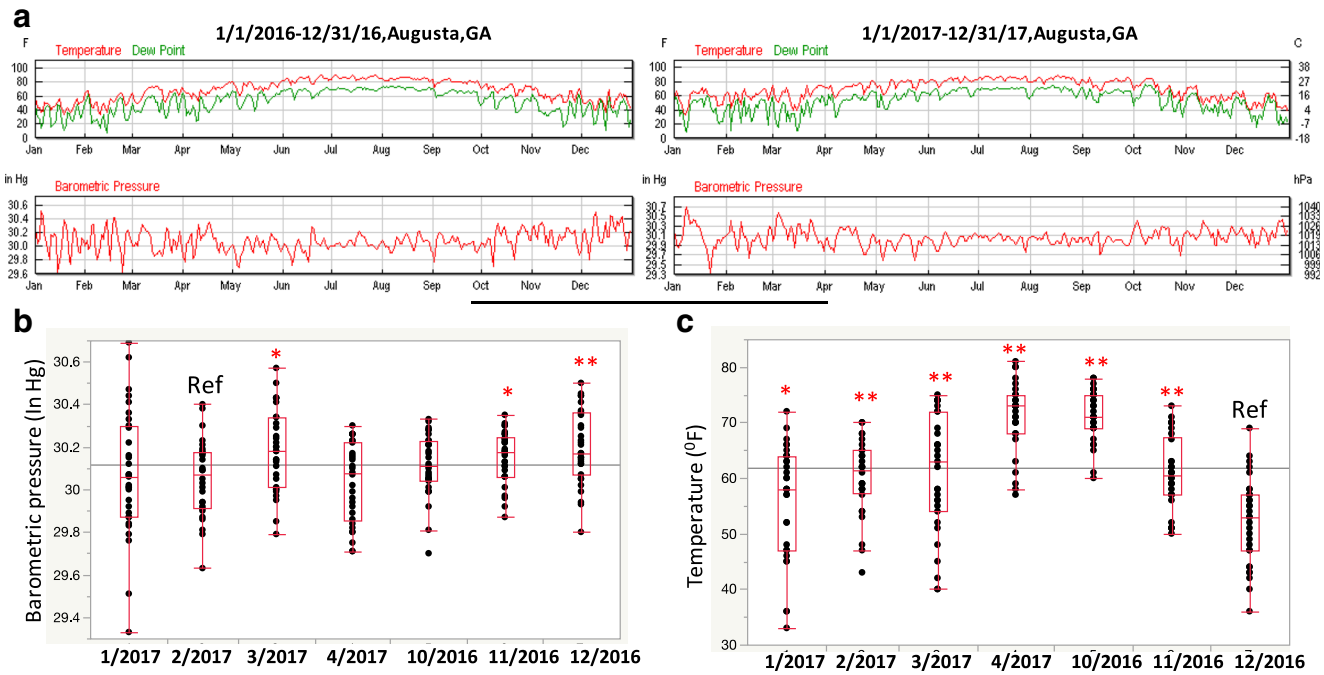

Fig. 2 Variations of barometric pressure and temperature in Augusta, GA, during 2016 and 2017. (**a**) Seasonal variation of barometric pressure and temperature in Augusta, GA, during 2016 and 2017 (https://www.wunderground.com/history).The study period was highlighted from October 1, 2016, to April 30, 2017. The barometric pressure and temperature showed more variation in fall and winter seasons compared with those in spring and summer seasons in the area of Augusta, GA. (**b**) Monthly variation of barometric pressure during 10/1/2016–4/30/2017. *$P < 0.05$, **$P < 0.01$ compared with that in February of 2017. (**c**) Monthly variation of temperature. *$P < 0.05$, **$P < 0.01$ compared with that in December of 2016 using non-parametric analyses (Kruskal-Wallis and Wilcoxon test)

Among the 240 inpatients with stroke admission diagnosis, there were 185 patients (77.1%) with risk factors (hypertension, diabetes mellitus, drinking alcohol, and smoking). Middle cerebral artery (MCA) (23.8%) occlusion was mostly influenced by the changes of barometric pressure compared with other locations followed by posterior cerebral artery (PCA) occlusion (7.5%), interior carotid artery (ICA) occlusion (5.0%), and anterior cerebral artery (ACA) occlusion (3.8%).

Table 1 Baseline characteristics of study subjects

Characteristics	Acute stroke ($n = 240$)
Age (years)	
< 18 (7.6 ± 6.1)	5 (2.1%)
< 65(51.8 ± 10.0)	109 (45.4%)
≥ 65 (76.6 ± 8.40)	126 (52.5%)
Gender	
Male (60.8 ± 17.1)	131 (54.6%)
Female (67.5 ± 17.0)	109 (45.4%)
Total (63.37 ± 24.75)	240 (100%)
Presence of risk factor history	$n = 185$ (77.1%)
Hypertension	156 (65%)
Diabetes mellitus	74 (30.8%)
Drinking alcohol	6 (2.5%)
Smoking	15 (6.3%)

Values are presented as mean ± standard deviation

Barometric Pressure and Temperature Variations

There was a significant association between the variations of barometric pressure and temperature ($P < 0.001$). Increased barometric pressure was associated with decreased temperature. There was also significant monthly variation of barometric pressure and temperature during the period of 10/1/2016 to 4/30/2017. The variations of barometric pressure and temperature are summarized in Fig. 2b. The investigators compared monthly mean barometric pressure to that in February. The mean values of barometric pressure in November, December, and March were significantly higher than that in February ($P < 0.05$). We compared monthly mean temperature to that in December. The mean values of temperature in October, November, January, February, March, and April were significantly higher than that in December ($P < 0.01$).

Association Between Barometric Pressure and Stroke Hospitalization

One hundred and thirty-seven days had ischemic stroke occurrence. The maximum number of strokes on a single day

Table 2 Association analysis between the independent variables and dependent variable

Independent variables	Dependent variable	Estimate	*P* value
BP mean	Stroke hospitalization	− 0.56	0.113
BP maximum change rate	Stroke hospitalization	− 2.98	0.532
BP variation between 24 h	Stroke hospitalization	− 1.29	0.007**
Temperature mean	Stroke hospitalization	0.003	0.693
Temperature maximum change rate	Stroke hospitalization	− 0.023	0.742
Temperature variation	Stroke hospitalization	0.0219	0.036*
BP variation × temperature variation	Interaction	− 0.0130	0.8453

Association analysis between the independent variables and dependent variable with zero-inflated Poisson model. *BP*, barometric pressure. *$P < 0.05$, **$P < 0.01$

was five. There was a significantly inverse correlation between daily variation of barometric pressure and daily stroke admission ($P < 0.01$). Decreased barometric pressure was associated with increased number of ischemic stroke admissions in the same day. Daily barometric pressure decreased one unit; daily number of ischemic stroke admission increased

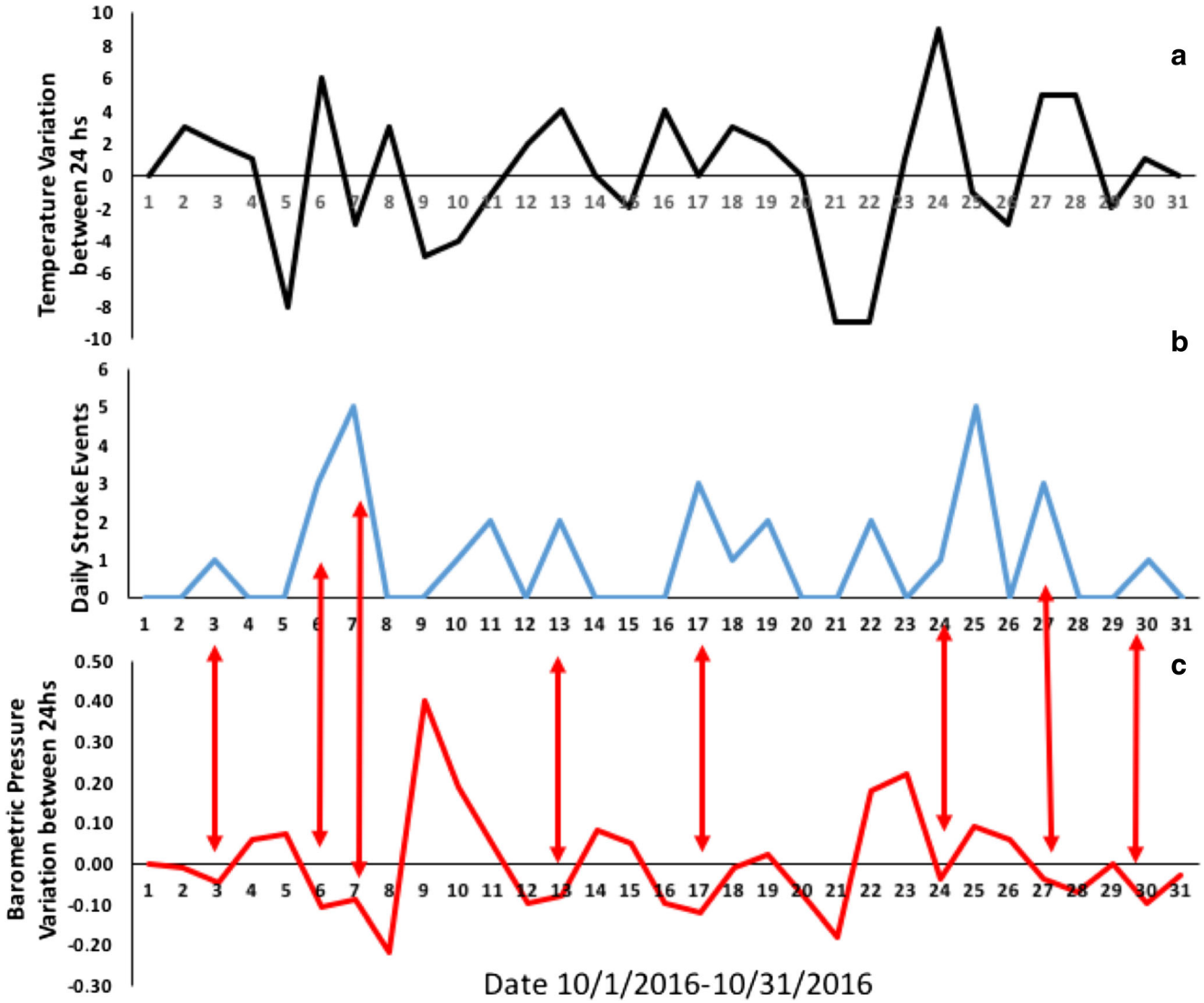

Fig. 3 Exposure-response curves between barometric pressure variation, temperature variation, and stroke events. (**a**) Temperature variation between 24 h vs date. (**b**) Daily stroke admission vs date. (**c**) Barometric pressure variation between 24 h vs date. Red arrow means decreased barometric pressure which corresponds to increased stroke hospitalization

Table 3 Delayed effect of temperature on stroke hospitalization

Temperature variation vs stroke hospitalization	Estimate	*P* value
Day 0	0.0219	0.036*
Day 1	0.0204	0.0843
Day 2	− 0.0112	0.3510
Day 3	− 0.0092	0.4029

Delayed effect analysis of temperature and stroke hospitalization with zero-inflated Poisson model. *$P < 0.05$

1.3 unit. No significant association was observed between the mean value and maximum change rate with 24 h and daily stroke admissions. There was no interaction between variations of barometric pressure and temperature as for the effect on stroke admissions ($P > 0.05$). Poisson correlation between daily barometric pressure, temperature, and daily stroke hospitalization is summarized in Table 2. Response-exposure curve between barometric pressure and stroke occurrence is documented in Fig. 3.

Association Between Temperature and Stroke Hospitalization

There was a significantly positive correlation between the variation of temperature and daily stroke admission ($P < 0.05$). Increased temperature was associated with increased stroke admission in the same day. There was no significant association between the mean value and maximum change rate and daily stroke admission. Estimation of potential delayed effect of temperature on stroke admission is summarized in Table 3 and Fig. 3. Temperature variation was positively associated with day 0 and day 1 stroke admissions and inversely associated with day 2 and day 3 stroke admissions. However, only the association between stroke admission of day 0 and temperature variation showed statistical significance. The results showed a nonlinear relationship between the temperature and stroke incidence.

Relative Risk of Risk Factors

The relative risk (RR) was calculated to determine the risk of having stroke events in patients with risk factors (hypertension, diabetes mellitus, drinking alcohol, smoking) compared with those without risk factors. The calculated RR was reported to be 3.34, indicating that the relative risk of having stroke events for patients with risk factors is about three times compared with those without risk factors (Table 4). Stroke events were more likely to occur in the patients with risk factors than in those without risk factors when exposed to barometric pressure and temperature changes.

Discussion

This retrospective observation study shows that decreased barometric pressure is associated with increased stroke admission, which is consistent with previous studies [3, 7–10]. Our results suggest that variation of barometric pressure can be used to predict the acute ischemic stroke hospitalization and thus evaluate the workload change of neurological intense care unit.

The correlation analysis (stratification) of age, gender, risk factor, and different occlusion locations shows that elder male patients (> 65) with hypertension or diabetes mellitus are more easily effected by rapid barometric pressure changes especially on MCA stroke admission.

The interaction effect of barometric pressure and temperature on daily stroke admission did not show statistically significant interaction between temperature and barometric pressure, even though decreased barometric pressure was associated with increased temperature. Moreover, temperature shows a positive correlation with stroke admission, which is consistent with previous studies [2, 5, 7, 11, 12]. However, the effect of temperature on stroke hospitalization may not be simply explained by regression analysis; it may show "U" or "J" shape relationships instead of a linear shape. Special mathematics model may be needed to further analyze the association between the temperature and stroke hospitalization.

Exposure-response curve (Fig. 3) shows prompt effect of barometric pressure on stroke admissions. However, prompt positive and potential delayed inverse (2–3 day lag) effect of temperature on stroke admission is also observed in the study. Our findings show the potential nonlinear relationship of temperature and stroke hospitalization is in line with that in the study by Marco et al. [3].

Weather conditions cause some pathophysiological changes. Atmospheric pressure may directly influence vessel walls, triggering endogenous inflammatory mechanisms and changing their endothelial function [8]. Cooling temperature is associated with increased erythrocyte and platelet counts, blood

Table 4 Relative risk of stroke hospitalization

Stroke Hospitalization	Patients with risk factors	Patients without risk factors
Total number (240)	185	55
Percentage	77.1	23.1
Relative risk	RR = 77.1%/23.1% = 3.34	

The calculated relative risk (RR) was reported to be 3.34 comparing the percentage of patients with risk factors and that of patients without risk factors

viscosity, artery pressure, plasma cholesterol and fibrinogen concentration, and induced vasoconstriction [13–15]. High temperature may increase level of coagulation factors [15].

Limitation

The sample size of this study was 240 patients. A large community center study which includes more patients, covers several years, and includes patients from nearby hospitals (University Hospital and Veteran Affair Hospital) would better explain the relationship between weather parameters and stroke occurrence in the area of Augusta, GA.

Conclusion

In conclusion, our study reveals correlations between weather parameters and stroke admission in Augusta, GA. Lower barometric pressure and higher temperature are associated with the increase number of ischemic stroke hospitalization. These associations are more prominent in men and older patients with hypertension or diabetes mellitus. These findings may enhance our understanding of relationship between stroke and weather and may be used in the development of public health strategies to minimize the weather-related stroke risk. Our study firstly documents the relationship of weather conditions (barometric pressure and temperature) and stroke hospitalization as well as the interaction effect of barometric pressure and temperature in the area of Augusta, GA. Further prospective studies are required to investigate the pathophysiological effect of weather on stroke occurrence.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Since this study was a retrospective study, informed consent was not required.

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