Risk Management and Healthcare Policy

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ORIGINAL RESEARCH

Daily Meteorological Parameters Influence the Risk of Intracerebral Hemorrhage in a Subtropical Monsoon Basin Climate

Peng Wang[1,*]
Shuwen Cheng[1,*]
Weizheng Song[1]
Yaxin Li[2]
Jia Liu[1]
Qiang Zhao[1]
Shuang Luo[1]

[1]Department of Neurosurgery, Chengdu Fifth People's Hospital/Affiliated Chengdu No.5 People's Hospital of Chengdu University of TCM, Chengdu, People's Republic of China; [2]West China Fourth Hospital/West China School of Public Health, Sichuan University, Chengdu, People's Republic of China

*These authors contributed equally to this work

Background and Purpose: The correlation between meteorological parameters and intracerebral hemorrhage (ICH) occurrence is controversial. Our research explored the effect of daily meteorological parameters on ICH risk in a subtropical monsoon basin climate.

Methods: We retrospectively analyzed patients with ICH in a teaching hospital. Daily meteorological parameters including temperature (TEM), atmospheric pressure (PRE), relative humidity (RHU), and sunshine duration (SSD) were collected, with the diurnal variation (daily maximum minus minimum) and day-to-day variation (average of the day minus the previous day) calculated to represent their fluctuation. We adopted a time-stratified case-crossover approach and selected conditional logistic regression to explore the effect of meteorological parameters on ICH risk. The influence of monthly mean temperature proceeded via stratified analysis. Air pollutants were gathered as covariates.

Results: Our study included 1052 eligible cases with ICH. In a single-factor model, the risk of ICH decreased by 5.9% ($P<0.001$) for each 1°C higher of the daily mean TEM, and the risk increased by 2.4% ($P=0.002$) for each 1hPa higher of the daily mean PRE. Prolongation of daily SSD inhibited the risk of ICH, and OR was 0.959 ($P=0.007$). The risk was raised by 7.5% ($P=0.0496$) with a 1°C increment of day-to-day variation of TEM. In a two-factor model, the effect of daily mean TEM or daily SSD on ICH risk was still statistically significant after adjusting another factor. The influence of meteorological parameters on ICH risk continued in cold months but disappeared in warm months after stratified analysis.

Conclusion: This research indicates daily TEM and SSD had an inverse correlation to ICH risk in a subtropical monsoon basin climate. They were independent when adjusted by another factor. Daily PRE and day-to-day TEM variation were positively related to ICH risk. The correlation of daily meteorological factors on ICH risk was affected by the monthly thermal background.

Keywords: intracerebral hemorrhage, temperature, atmospheric pressure, relative humidity, sunshine duration

Introduction

Intracerebral hemorrhage (ICH) is a hemorrhagic subtype of stroke, which has a higher incidence in the Asian population when compared with the European population.[1] Although accounting for only 10–20% of all strokes, it brings worse clinical prognosis and more global burden than ischemic stroke.[2,3] The patients who suffer from the disease usually have a sudden onset and deteriorating clinical conditions, accompanied by excessive hospital stays and high medical costs. The proportion of death or disability

Correspondence: Shuang Luo
Department of Neurosurgery, Chengdu Fifth People's Hospital/Affiliated Chengdu No.5 People's Hospital of Chengdu University of TCM, 33# Mashi Street, Wenjiang, Chengdu, People's Republic of China
Tel/Fax +86 28 82726171
Email luoshuang2000@126.com

Received: 14 September 2021
Accepted: 2 November 2021
Published: 1 December 2021

can reach 37.7–40.4% in ICH cases,[4,5] and 12-39% of patients can recover their self-care ability at six months or later.[4] Therefore, analyzing the risk factors of this disease and taking appropriate preventive measures to reduce the disease incidence is a high priority.

In addition to the traditional risk factors such as hypertension and smoking, recent studies reveal that meteorological parameters and air pollutants are the environmental risk factors of ICH.[6,7] Many researchers indicate that changes in meteorological parameters, including temperature (TEM), atmospheric pressure (PRE), and relative humidity (RHU), are significantly related to the risk of ICH.[8–10] However, some scholars have opposite opinions on these views.[11–13] Moreover, the influence type of meteorological parameters on ICH occurrence is controversial. For instance, some studies believe that high PRE increases the risk of ICH,[14,15] but others suggest that low PRE precipitates ICH risk.[16,17] One of the reasons for this inconsistency is that these studies proceeded under different climatic conditions.

Chengdu, the biggest city in the Sichuan Basin, has a subtropical monsoon climate and four distinct seasons, with characteristics of low wind speed, high humidity, and less sunshine all year round. The permanent resident population was 20.9 million as of November 1, 2020. (http://tjj.sc.gov.cn) A study conducted in the city shows that seasonal variation influences the incidence of ICH. This impact is independent of traditional risk factors.[18] However, the correlation between daily meteorological parameters and the risk of ICH occurrence is unclear in this subtropical monsoon basin climate. The role of background meteorological conditions, such as monthly mean TEM, is also unknown. The present research aimed to discuss the correlation between daily meteorological parameters and ICH onset risk in the basin climate, using a time-stratified case-crossover approach. Further stratified analysis proceeded to explore the influence of monthly mean TEM on this correlation. We included TEM, PRE, RHU, sunshine duration (SSD) as explanatory variables and selected air pollutants as covariates.

Materials and Methods

Clinical Data

We retrospectively analyzed patients with ICH in a teaching hospital from January 1, 2014, to December 31, 2019. The hospital, located in the west of the city, is the nearest large medical center to the national benchmark climate station (east longitude 103.52° and north latitude 30.45°) in Chengdu. The straight-line distance between the hospital and the climate station is 6.4km. Participants were patients with I61 coding (ICD-10). Cases were excluded if they had macro-cerebrovascular diseases, attacks outside Chengdu, unclear onset time, or a lack of clinical data. We collected patients' clinical information (gender, age, admission time, and symptom onset time) via an electronic medical record system. The study protocol was approved by the institutional ethics committee (ref. no. 2019–085).

Meteorological Parameters and Air Pollutants

Daily meteorological parameters during the study period were collected, including daily TEM (mean, maximum and minimum), daily PRE (mean, maximum and minimum), daily mean RHU, and daily SSD. The meteorological parameters fluctuation referred to the diurnal variation (the maximum of the day minus the minimum) and the day-to-day variation (the absolute value of the mean in the day minus the one in the previous day). We divided the research period into cold months and warm months. The cold months were defined as that the monthly mean TEM was less than 20°C, and the warm months were defined as the monthly mean TEM was equal to or greater than 20°C. The meteorological data were from the Chinese Meteorological Data Center (http://data.cma.cn/).

The main types of air pollutants in Chengdu are $PM_{2.5}$, NO_2, and O_3. These three pollutants were included as covariates, considering the impact of air pollutants on ICH onset. The pollutants data were from the Chengdu Ecological and Environment Bureau (http://sthj.chengdu.gov.cn/).

Study Design

We adopted a time-stratified case-crossover approach in this research. This method investigates the risk factors' exposure degree at the time of the target event occurrence compared with the exposure degree before or after, using patients themselves as control. It can determine whether the risk factors are related to the event and judge the degree of relevance. The confounding factors related to individual characteristics (such as age, gender, genetic factors) minimize satisfactorily.[19] In our study, the case days were the days of symptom onset (lag0). The control days were the other corresponding days in the same month with seven days as the interval. We took symptom onset as the target event to eliminate the misjudgment of the time of disease occurrence. We also included the data of 2 days before the symptom onset to know whether a lag effect occurred. Lag1 referred to the day before lag0, and lag2 referred to the day before lag1. The choice of lag1 and lag2 in the control days was consistent with that in the case days.

Statistical Analysis

Numerical variables were expressed as mean (±SD) or median (25–75%), and categorical variables were represented as frequency and percentage. Spearman correlation analysis was used to detect the correlation between meteorological parameters and air pollutants. We adopted conditional logistic regression analysis to explore the effect of daily meteorological parameters and their fluctuations on ICH occurrence. The influence of monthly mean TEM was also studied in cold and warm months, separately. Results were reported as odds ratios (OR) and 95% confidence intervals (CI). We applied R software (4.0.3) and GraphPad (9.0.0) for statistical analysis and drawing, and the difference was statistically significant when $P<0.05$.

Results

From January 1, 2014, to December 31, 2019, 1052 cases met the inclusion and exclusion criteria were included in this study. The patients were 693 males and 359 females, ranging in age from 20 to 93 years. 58.7% of the patients were ≥60 years old. We included 72 months of meteorological parameters and pollutants data for analysis (Table 1). Based on the monthly mean TEM, our study period had 43 cold months and 29 warm months. Spearman correlation analysis revealed that the coefficient between daily mean TEM and maximum TEM, and the coefficient between daily mean TEM and minimum TEM, were greater than 0.9. The coefficient between daily mean PRE and maximum PRE, the coefficient between daily mean PRE and minimum PRE, and the coefficient between daily maximum PRE and minimum PRE, also exceeded 0.9 (Figure 1 and Table S1).

Three daily meteorological parameters (TEM, PRE, and SSD) produced a meaningful effect on the risk of ICH onset in a single-factor model (Figure 2A). The increase of daily TEM (mean, maximum and minimum) reduced the risk of ICH. For instance, the risk of ICH decreased by 5.9% ($P<0.001$) when the daily mean TEM increased by 1 °C. On the contrary, the increase of PRE (mean, maximum and minimum) promoted ICH occurrence. For example, the risk of ICH increased by 2.4% ($P=0.002$) when the daily mean PRE increased by 1hPa.

Table 1 Statistical Descriptions of Meteorological Parameters and Air Pollutants Between December 30, 2013, and December 31, 2019, in Chengdu

Variables	Units	Min	P25	P50	P75	Max	IQR
Daily meteorological parameters							
Daily mean TEM	°C	−1.9	9.8	17.3	22.9	29.8	13.1
Daily max TEM	°C	3.1	14.3	22.0	28.0	36.7	13.7
Daily min TEM	°C	−6.5	7.3	14.2	19.7	25.9	12.4
Daily mean PRE	hPa	932.5	944.9	950.9	956.9	977.0	12.0
Daily max PRE	hPa	936.3	946.9	953.6	959.5	980.4	12.6
Daily min PRE	hPa	928.7	942.2	948.2	953.8	973.3	11.6
Daily mean RHU	%	42.0	77.0	83.0	89.0	99.0	12.0
Daily SSD	h	0.0	0.0	1.1	5.4	12.6	5.4
Meteorological parameters fluctuation							
Diurnal variation of TEM	°C	0.7	4.8	7.6	10.9	20.0	6.1
Diurnal variation of PRE	hPa	1.7	3.9	4.9	6.2	16.7	2.3
Day-to-day variation of TEM	°C	0.0	0.4	0.9	1.7	5.6	1.3
Day-to-day variation of PRE	hPa	0.0	0.8	1.8	3.2	16.0	2.4
Day-to-day variation of RHU	%	0.0	2.0	5.0	9.0	43.0	7.0
Day-to-day variation of SSD	h	0.0	0.1	1.8	4.4	12.6	4.3
Air Pollutants							
$PM_{2.5}$	μg/m³	4.0	30.0	46.0	73.0	396.0	43.0
NO_2	μg/m³	12.0	38.0	48.0	59.0	121.0	21.0
O_3	μg/m³	4.0	49.0	78.0	124.0	300.0	75.0

Abbreviations: TEM, temperature; PRE, atmospheric pressure; RHU, relative humidity; SSD, sunshine duration; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤2.5μm; NO_2, nitrogen dioxide; O_3, ozone; IQR, interquartile range.

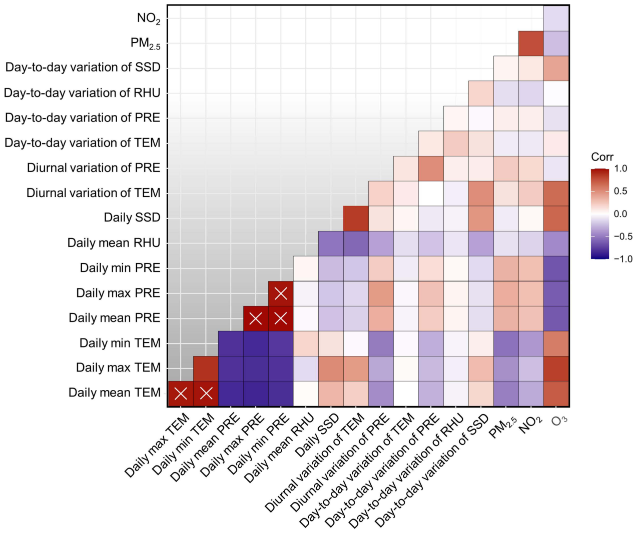

Figure 1 Spearman correlation analysis of meteorological parameters and air pollutants. The correlation coefficient of two variables marked as "×" is greater than 0.9.

Abbreviations: TEM, temperature; PRE, atmospheric pressure; RHU, relative humidity; SSD, sunshine duration; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤2.5μm; NO_2, nitrogen dioxide; O_3, ozone; Corr, correlation coefficient.

We also found that prolongation of daily SSD in lag2 reduced the risk of ICH (OR=0.959, *P*=0.007). In addition, two consecutive days of TEM variation significantly accelerated the risk of ICH occurrence. The risk increased by 7.5% (*P*=0.0496) with a 1°C increase of day-to-day variation of TEM in lag0.

We established a two-factor model to understand which factors may affect ICH onset independently of other factors. To avoid collinearity and model distortion, we did not simultaneously include two variables were if their correlation coefficient exceeded 0.9.[20] In this model, two meteorological parameters persistently affected the risk of ICH after adjusting other factors (Table 2). The effect of daily mean TEM on ICH risk in lag0 was statistically significant when daily mean PRE, RHU, or SSD was adjusted. The effect of daily SSD on ICH risk in lag2 was also statistically significant when including daily mean TEM, PRE, or RHU as adjustment parameters. However, the day-to-day variation of TEM insignificantly related to ICH risk after adjusting the day-to-day variation of PRE or RHU (Table 3). The diurnal variation of TEM and PRE had meaningless relation to the risk of ICH occurrence regardless of another factor was adjusted (data not shown).

Further stratified analysis based on the monthly mean TEM in the single-factor model was conducted (Figure 2B and C). In cold months, many meteorological parameters affected ICH onset meaningfully. The daily TEM and PRE had a significant impact on the risk of ICH occurrence. The risk decreased by 5.7% (*P*=0.001) with a 1°C increment of daily mean TEM, and the risk increased by 2.4% (*P*=0.002) when the daily mean PRE increased by 1hPa. The diurnal variation of TEM, diurnal or day-to-day variation of PRE, also accelerated the risk of ICH significantly. The risk increased by 4.1% (*P*=0.014) with a 1°C elevation of diurnal variation of TEM. And the risk was raised by 5.9% (*P*=0.006) and 4.2% (*P*=0.032) when the diurnal variation of PRE and day-to-day variation of PRE increased by 1hPa, respectively. By contrast, daily meteorological parameters and their fluctuation did not correlate with the risk of ICH in warm months except the daily max TEM.

Figure 3 summarizes the relationship between daily meteorological parameters and the risk of ICH onset in this study.

Discussion

Our research explored the effect of daily meteorological parameters on the risk of ICH occurrence in a subtropical monsoon basin climate. The main findings are 1) daily TEM, PRE, SSD, and day-to-day variation of TEM were related to the risk of ICH. The maximum OR occurred on the day of symptom onset except for SSD. 2) In the two-factor model, the correlation of daily mean TEM and SSD on ICH risk was not affected by other meteorological factors. 3) The influence of meteorological factors on ICH risk continued in cold months but decreased in warm months.

TEM is a noticed meteorological parameter affecting ICH occurrence. Most studies from different climate types show that TEM negatively correlates with ICH risk,[8,9,14,16,21–25] although a few studies suggest that TEM is not a risk factor.[11–13] In the present research, we found daily mean TEM and day-to-day variation of TEM influenced the risk of ICH meaningfully in the single-factor model. And the daily mean TEM in lag0 still influenced ICH risk after adjusting other factors in the two-factor model. However, the correlation between the day-to -day variation of TEM and ICH risk disappeared when taking the day-to-day variation of PRE or RHU as adjustment parameters, respectively. This result suggested that the daily mean TEM was an independent factor affecting the risk of ICH. In addition, we conducted a stratified analysis according to the monthly mean TEM to study the effect of the thermal background. The outcome revealed that daily mean TEM influenced the ICH

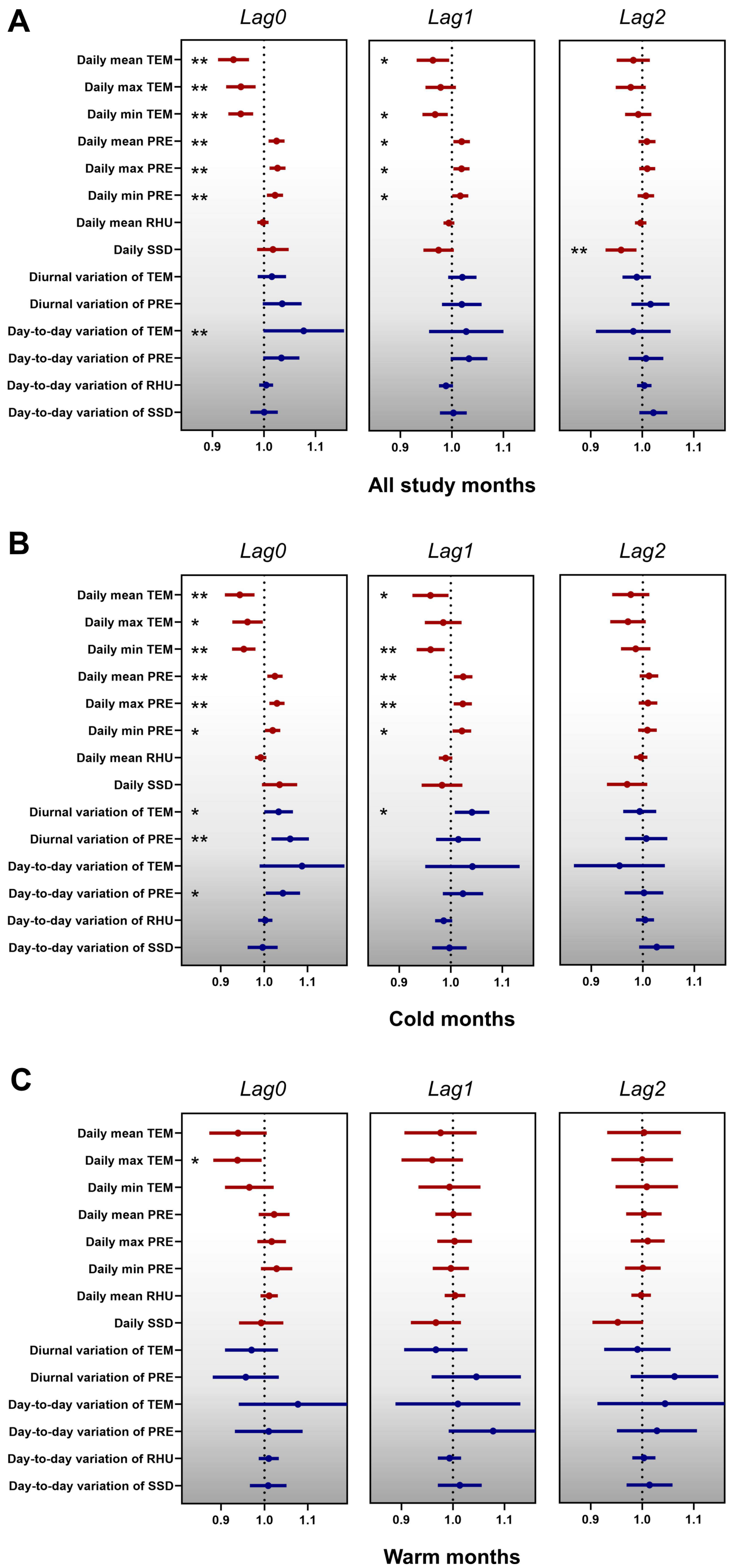

Figure 2 The forest diagram shows the effect of daily meteorological parameters on intracerebral hemorrhage (ICH) occurrence risk in the single-factor model. The red line represents daily meteorological parameters, and the blue line represents meteorological parameters fluctuation. (**A**) Odds ratios of ICH onset risk in all study months. (**B**) Odds ratios of ICH onset risk in cold months. (**C**) Odds ratios of ICH onset risk in warm months. *$P<0.05$; **$P<0.01$.

Abbreviations: TEM, temperature; PRE, atmospheric pressure; RHU, relative humidity; SSD, sunshine duration.

Table 2 The Effect of Daily Meteorological Parameters on the ICH Onset Risk for All Study Months in the Two-Factor Model (or, 95% CI)

Variables	Adjusted for Daily Mean TEM	Adjusted for Daily Mean PRE	Adjusted for Daily Mean RHU	Adjusted for Daily SSD
Lag0				
Daily mean TEM	—	0.953 (0.916, 0.991) *	0.941 (0.911, 0.971) **	0.942 (0.912, 0.973) **
Daily mean PRE	1.010 (0.991, 1.030)	—	1.025 (1.009, 1.041) **	1.023 (1.008, 1.040) **
Daily mean RHU	0.998 (0.987, 1.009)	1.001 (0.990, 1.012)	—	0.999 (0.988, 1.010)
Daily SSD	1.007 (0.976, 1.038)	1.009 (0.979, 1.041)	1.017 (0.986, 1.048)	—
Lag1				
Daily mean TEM	—	0.978 (0.940, 1.018)	0.963 (0.933, 0.995) *	0.957 (0.926, 0.989) **
Daily mean PRE	1.013 (0.994, 1.032)	—	1.018 (1.002, 1.035) *	1.022 (1.006, 1.038) **
Daily mean RHU	0.995 (0.984, 1.005)	0.997 (0.986, 1.008)	—	0.993 (0.982, 1.004)
Daily SSD	0.967 (0.938, 0.998) *	0.967 (0.938, 0.998) *	0.971 (0.942, 1.002)	—
Lag2				
Daily mean TEM	—	0.990 (0.951, 1.029)	0.982 (0.951, 1.015)	0.976 (0.944, 1.009)
Daily mean PRE	1.006 (0.987, 1.026)	—	1.009 (0.993, 1.025)	1.014 (0.997, 1.030)
Daily mean RHU	0.997 (0.986, 1.008)	0.998 (0.987, 1.009)	—	0.994 (0.983, 1.005)
Daily SSD	0.956 (0.926, 0.986) **	0.954 (0.925, 0.985) **	0.956 (0.927, 0.986) **	—

Notes: *$P<0.05$; **$P<0.01$.
Abbreviations: TEM, temperature; PRE, atmospheric pressure; RHU, relative humidity; SSD, sunshine duration; OR, odds ratio; CI, confidence interval.

Table 3 The Effect of Day-to-Day Variation of Meteorological Parameters on the ICH Onset Risk for All Study Cases in the Two-Factor Model (or, 95% CI)

Variables	Adjusted for Day-to-Day Variation of TEM	Adjusted for Day-to-Day Variation of PRE	Adjusted for Day-to-Day Variation of RHU	Adjusted for Day-to-Day Variation of SSD
Lag0				
Day-to-day variation of TEM	—	1.064 (0.989, 1.146)	1.073 (0.997, 1.156)	1.076 (1.000, 1.157) *
Day-to-day variation of PRE	1.028 (0.993, 1.064)	—	1.032 (0.998, 1.068)	1.033 (0.999, 1.069)
Day-to-day variation of RHU	1.002 (0.988, 1.016)	1.003 (0.990, 1.017)	—	1.005 (0.991, 1.018)
Day-to-day variation of SSD	0.998 (0.971, 1.025)	1.001 (0.975, 1.028)	0.999 (0.972, 1.026)	—
Lag1				
Day-to-day variation of TEM	—	1.014 (0.944, 1.089)	1.042 (0.970, 1.120)	1.026 (0.955, 1.101)
Day-to-day variation of PRE	1.032 (0.996, 1.068)	—	1.036 (1.001, 1.072) *	1.033 (0.998, 1.069)
Day-to-day variation of RHU	0.987 (0.973, 1.001)	0.988 (0.974, 1.001)	—	0.988 (0.974, 1.002)
Day-to-day variation of SSD	1.001 (0.975, 1.028)	1.004 (0.978, 1.030)	1.008 (0.982, 1.036)	—
Lag2				
Day-to-day variation of TEM	—	0.977 (0.906, 1.053)	0.974 (0.903, 1.051)	0.975 (0.905, 1.050)
Day-to-day variation of PRE	1.009 (0.975, 1.044)	—	1.006 (0.973, 1.041)	1.008 (0.974, 1.042)
Day-to-day variation of RHU	1.005 (0.991, 1.019)	1.004 (0.990, 1.017)	—	1.002 (0.988, 1.016)
Day-to-day variation of SSD	1.022 (0.996, 1.050)	1.021 (0.995, 1.049)	1.021 (0.994, 1.048)	—

Note: *$P<0.05$.
Abbreviations: TEM, temperature; PRE, atmospheric pressure; RHU, relative humidity; SSD, sunshine duration; OR, odds ratio; CI, confidence interval.

occurrence markedly in cold months but failed in warm months, which indicated that the correlation between TEM and ICH risk was affected by monthly background TEM.

The fluctuation of TEM in the present study may represent a cold wave (usually in cold months) or a heatwave (usually in warm months). We found that the effect of daily TEM fluctuation on ICH risk only occurred in cold months but disappeared in warm months after stratified analysis. These results suggest that cold wave, mainly occurring in cold months, is the main factor causing ICH. This result is consistent with the previous researches from Italy and Taiwan.[21,26] As for heatwave,

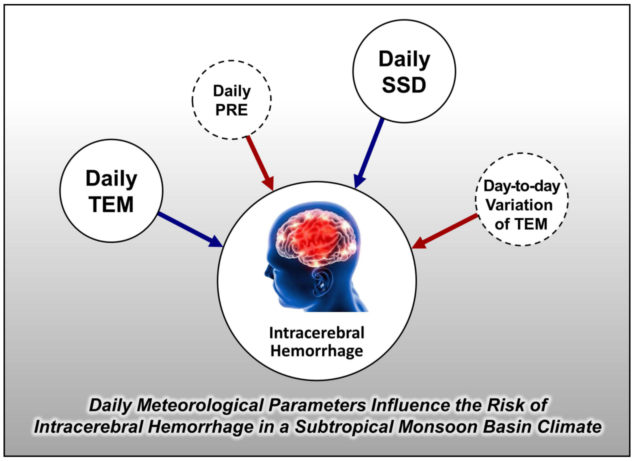

Figure 3 Summary of the relationship between daily meteorological parameters and intracerebral hemorrhage (ICH) onset risk in a subtropical monsoon basin climate. The blue solid line indicates that the parameter negatively correlated with the ICH occurrence, and the red solid line represents a positive correlation between the parameter and ICH onset. The black solid circle means the parameter is an independent risk factor, and the black dotted circle shows the parameter is a non-independent risk factor.

Abbreviations: TEM, temperature; PRE, atmospheric pressure; SSD, sunshine duration.

it is an environmental risk factor of cerebral infarction reported in a recent study from Beijing.[25] The possible mechanism of low ambient TEM on ICH pathogenesis is that the drop in ambient TEM can prompt blood pressure to increase, which is a crucial inducement of ICH.[7] The decrease of TEM can cause sympathetic excitation, increase the secretion of adrenocortical and thyroid hormones, and activate the renin–angiotensin system simultaneously. The above physiological changes constrict peripheral blood vessels and increase blood flow resistance, leading individual blood pressure to increase consequently.[7,27]

PRE is another risk factor impacting ICH occurrence. Some studies find that PRE positively correlates to the ICH attack,[14,15] but other scholars observe that the effect of PRE on ICH onset is negative[16,17] or irrelevant.[12,13] Our study found that high daily PRE had a significant impact on the ICH risk, and the variation of PRE also significantly promoted the risk in cold months. The inconsistency of the above researches may be related to the number of study cases, experimental design, statistical methods, and the climate characteristics of the study area. In the two-factor model, the influence of daily mean PRE on the risk of ICH was affected by daily mean TEM. This result indicated that PRE was not primarily associated with ICH risk in a subtropical monsoon basin climate. Our study also found that the effect of PRE on ICH risk disappeared in warm months, suggesting that this effect was influenced by monthly mean TEM. It may be due to the different PRE levels in warm months and cold months. In our study, the daily mean PRE was low (945.06hPa) in warm months but high (955.34hPa) in cold months (data not shown). Although some studies found a correlation between PRE and blood pressure,[28,29] the specific biological mechanism of PRE on ICH occurrence remains to be clarified.[15]

Our research did not find any correlation between RHU and the risk of ICH. This outcome is consistent with most previous studies.[11–13,21–24] However, an investigation from Chongqing, a southwest city in China, reveals that RHU is negatively correlated with the risk of ICH when RHU is greater than 75%.[8] But the author did not analyze the underlying causes of this phenomenon. Interestingly, our study found that daily SSD in lag2 had a positive influence on the risk of ICH onset. The risk decreased when daily SSD in lag2 was prolonged. The possible reason may be that extension of daily SSD can cause the increase of daily TEM. Nevertheless, the extension of daily SSD still reduced ICH risk after adjusting daily mean TEM in the two-factor model. This result suggested that there may be other biological mechanisms to explain the effect of SSD on ICH pathogenesis.

The present study used the time of symptoms onset rather than the time of admission or emergency room visit. This method helps to avoid the wrong estimation of the time of disease attack. Moreover, Chengdu is a megacity in southern China and has no large-scale central heating system. The indoor TEM in the city is closer to the outdoor TEM, and the correlation between outdoor TEM and ICH onset matches more directly in our study. However, our research did not construct a multivariable logistic regression model, although this model is closer to the patient's exposure in the real world. This is because we found that only daily TEM and SSD were associated with ICH risk in this study, which was independent of other factors. Considering the complex correlation between meteorological factors (SSD can lead to the rise of TEM) and the sensitivity of logistic regression to the collinearity of variables in the model, we did not further establish a multivariable equation.

Some limitations need to be noticed in this study. Firstly, we studied the correlation between daily meteorological parameters and ICH occurrence in a subtropical monsoon basin climate. The results of this study may be inapplicable to other climate types. Secondly, the meteorological parameters and air pollutant data used in this study were from fixed outdoor stations. The data may not fully represent the patient's indoor exposure, causing inaccurate estimates of individual exposure. Finally, some other environmental risk factors related to blood pressure, such as low noise and high altitude,[30] were not included in this study, which may confound our results.

In future research, there are some potential research directions. One is to verify whether there is a correlation between the risk of ICH and the ratio between night and day temperature in the day preceding ICH. This temperature variability in the day-night cycle is reported to be associated with further intracranial pressure in subarachnoid hemorrhage patients treated with hypothermia.[31] Another is to explore the correlation between geomagnetic fields and ICH risk. This magnetic field can act on human cryptochrome, a molecule involved in circadian rhythms and inflammation.[32] It has been found in clinical research that two days after geomagnetic storms, the risk of myocardial infarction with ST-elevation was over 1.5 times increased in some patients.[33]

Conclusions

We first studied the effects of daily meteorological factors on ICH onset risk in a subtropical monsoon base climate. The results indicated that both daily TEM and SSD had an inverse function on the risk of ICH. These two factors were independent when adjusted by another factor in the two-factor model. On the contrary, daily PRE and day-to-day TEM variation positively correlated with the ICH risk, but they were non-independent factors. The correlation of daily meteorological factors on ICH risk was affected by the monthly thermal background. The finding of our study may help healthcare authorities and the public take necessary prevention measures to cope with the adverse biological effects of climate, with a purpose to lower ICH onset risk.

Supplementary Material

The supplementary material (Table S1) for this article can be found online.

Ethics Approval and Consent to Participate

All procedures performed in this study were following the ethical standards of Ethics Committee of Chengdu Fifth People's Hospital (ref. no. 2019-085) and the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was not required since data were anonymized.

Acknowledgments

We thank Ms. Qing Qing, who graduated from Massey University in New Zealand, for her English editorial assistance.

Funding

This research was supported by grants from the Foundation of Sichuan Health Commission (19PJ016), and the Youth Innovation Project of Medical Scientific Research in Sichuan Province (Q19016).

Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Hostettler IC, Seiffge DJ, Werring DJ. Intracerebral hemorrhage: an update on diagnosis and treatment. *Expert Rev Neurother*. 2019;19(7):679–694. doi:10.1080/14737175.2019.1623671
2. Pinho J, Costa AS, Araujo JM, Amorim JM, Ferreira C. Intracerebral hemorrhage outcome: a comprehensive update. *J Neurol Sci*. 2019;398:54–66. doi:10.1016/j.jns.2019.01.013
3. Weimar C, Kleine-Borgmann J. Epidemiology, prognosis and prevention of non-traumatic intracerebral hemorrhage. *Curr Pharm Des*. 2017;23(15):2193–2196. doi:10.2174/1381612822666161027152234
4. van Asch CJ, Luitse MJ, Rinkel GJ, van der Tweel I, Algra A, Klijn CJ. Incidence, case fatality, and functional outcome of intracerebral haemorrhage over time, according to age, sex, and ethnic origin: a systematic review and meta-analysis. *Lancet Neurol*. 2010;9(2):167–176. doi:10.1016/S1474-4422(09)70340-0
5. Qureshi AI, Palesch YY, Barsan WG, et al. Intensive blood-pressure lowering in patients with acute cerebral hemorrhage. *N Engl J Med*. 2016;375(11):1033–1043. doi:10.1056/NEJMoa1603460
6. Zhang S, Zhang W, Zhou G. Extended risk factors for stroke prevention. *J Natl Med Assoc*. 2019;111(4):447–456. doi:10.1016/j.jnma.2019.02.004
7. Lavados PM, Olavarria VV, Hoffmeister L. Ambient temperature and stroke risk: evidence supporting a short-term effect at a population level from acute environmental exposures. *Stroke*. 2018;49(1):255–261. doi:10.1161/STROKEAHA.117.017838
8. Li X, Zhang JH, Qin X. Intracerebral hemorrhage and meteorological factors in Chongqing, in the southwest of China. *Acta Neurochir Suppl*. 2011;111:321–325. doi:10.1007/978-3-7091-0693-8_53
9. Zheng D, Arima H, Sato S, et al. Low ambient temperature and intracerebral hemorrhage: the INTERACT2 Study. *PLoS One*. 2016;11(2):e0149040. doi:10.1371/journal.pone.0149040
10. Herweh C, Nordlohne S, Sykora M, Uhlmann L, Bendszus M, Steiner T. Climatic and seasonal circumstances of hypertensive intracerebral hemorrhage in a worldwide cohort. *Stroke*. 2017;48(12):3384–3386. doi:10.1161/STROKEAHA.117.018779
11. Lim JS, Kwon HM, Kim SE, Lee J, Lee YS, Yoon BW. Effects of temperature and pressure on acute stroke incidence assessed using a Korean nationwide insurance database. *J Stroke*. 2017;19(3):295–303. doi:10.5853/jos.2017.00045

12. Neidert MC, Sprenger M, Mader M, et al. A high-resolution analysis on the meteorological influences on spontaneous intracerebral hemorrhage incidence. *World Neurosurg*. 2017;98:695–703 e619. doi:10.1016/j.wneu.2016.12.006
13. Illy E, Gerss J, Fischer BR, Stummer W, Brokinkel B, Holling M. Influence of meteorological conditions on the incidence of chronic subdural haematoma, subarachnoid and intracerebral haemorrhages - the "Bleeding Weather Hypothesis". *Turk Neurosurg*. 2020;30 (6):892–898. doi:10.5137/1019-5149.JTN.29821-20.2
14. Mukai T, Hosomi N, Tsunematsu M, et al. Various meteorological conditions exhibit both immediate and delayed influences on the risk of stroke events: the HEWS-stroke study. *PLoS One*. 2017;12(6): e0178223. doi:10.1371/journal.pone.0178223
15. Garg RK, Ouyang B, Pandya V, et al. The influence of weather on the incidence of primary spontaneous intracerebral hemorrhage. *J Stroke Cerebrovasc Dis*. 2019;28(2):405–411. doi:10.1016/j.jstrokecerebrovasdis.2018.10.011
16. Hori A, Hashizume M, Tsuda Y, Tsukahara T, Nomiyama T. Effects of weather variability and air pollutants on emergency admissions for cardiovascular and cerebrovascular diseases. *Int J Environ Health Res*. 2012;22(5):416–430. doi:10.1080/09603123.2011.650155
17. Honig A, Eliahou R, Pikkel YY, Leker RR. Drops in barometric pressure are associated with deep intracerebral hemorrhage. *J Stroke Cerebrovasc Dis*. 2016;25(4):872–876. doi:10.1016/j.jstrokecerebrovasdis.2015.11.027
18. Wang K, Li H, Liu W, You C. Seasonal variation in spontaneous intracerebral hemorrhage frequency in Chengdu, China, is independent of conventional risk factors. *J Clin Neurosci*. 2013;20 (4):565–569. doi:10.1016/j.jocn.2012.02.052
19. 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(6):717–726. doi:10.1097/01.ede.0000181315.18836.9d
20. Nhung NTT, Schindler C, Chau NQ, et al. Exposure to air pollution and risk of hospitalization for cardiovascular diseases amongst Vietnamese adults: case-crossover study. *Sci Total Environ*. 2020;703:134637. doi:10.1016/j.scitotenv.2019.134637
21. Morabito M, Crisci A, Vallorani R, Modesti PA, Gensini GF, Orlandini S. Innovative approaches helpful to enhance knowledge on weather-related stroke events over a wide geographical area and a large population. *Stroke*. 2011;42(3):593–600. doi:10.1161/STROKEAHA.110.602037
22. Ishikawa K, Niwa M, Tanaka T. Difference of intensity and disparity in impact of climate on several vascular diseases. *Heart Vessels*. 2012;27(1):1–9. doi:10.1007/s00380-011-0206-5
23. Han MH, Yi HJ, Ko Y, Kim YS, Lee YJ. Association between hemorrhagic stroke occurrence and meteorological factors and pollutants. *BMC Neurol*. 2016;16:59. doi:10.1186/s12883-016-0579-2
24. Zheng Y, Wang X, Liu J, Zhao F, Zhang J, Feng H. A community-based study of the correlation of hemorrhagic stroke occurrence with meteorologic factors. *J Stroke Cerebrovasc Dis*. 2016;25(10):2323–2330. doi:10.1016/j.jstrokecerebrovasdis.2014.12.028
25. Ma P, Zhou J, Wang S, et al. Differences of hemorrhagic and ischemic strokes in age spectra and responses to climatic thermal conditions. *Sci Total Environ*. 2018;644:1573–1579. doi:10.1016/j.scitotenv.2018.07.080
26. Fang CW, Ma MC, Lin HJ, Chen CH. Ambient temperature and spontaneous intracerebral haemorrhage: a cross-sectional analysis in Tainan, Taiwan. *BMJ Open*. 2012;2(3):e000842. doi:10.1136/bmjopen-2012-000842
27. Yu B, Jin S, Wang C, et al. The association of outdoor temperature with blood pressure, and its influence on future cardio-cerebrovascular disease risk in cold areas. *J Hypertens*. 2020;38(6):1080–1089. doi:10.1097/HJH.0000000000002387
28. Kaminski M, Cieslik-Guerra UI, Kotas R, et al. Evaluation of the impact of atmospheric pressure in different seasons on blood pressure in patients with arterial hypertension. *Int J Occup Med Environ Health*. 2016;29(5):783–792. doi:10.13075/ijomeh.1896.00546
29. Azcarate T, Mendoza B. Influence of geomagnetic activity and atmospheric pressure in hypertensive adults. *Int J Biometeorol*. 2017;61 (9):1585–1592. doi:10.1007/s00484-017-1337-x
30. Brook RD. The environment and blood pressure. *Cardiol Clin*. 2017;35(2):213–221. doi:10.1016/j.ccl.2016.12.003
31. Nogueira AB, Annen E, Boss O, Farokhzad F, Sikorski C, Keller E. Temperature variability in the day-night cycle is associated with further intracranial pressure during therapeutic hypothermia. *J Transl Med*. 2017;15(1):170. doi:10.1186/s12967-017-1272-y
32. Nogueira AB, Nogueira AB, Veiga JCE, Teixeira MJ. Hypothesis on the role of cryptochromes in inflammation and subarachnoid hemorrhage outcome. *Front Neurol*. 2017;8:637. doi:10.3389/fneur.2017.00637
33. Vencloviene J, Babarskiene R, Slapikas R, Sakalyte G. The association between phenomena on the sun, geomagnetic activity, meteorological variables, and cardiovascular characteristic of patients with myocardial infarction. *Int J Biometeorol*. 2013;57(5):797–804. doi:10.1007/s00484-012-0609-8