

Extreme temperature increases the severity of intracerebral hemorrhage: An analysis based on the cold region of China

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Abstract

Objective: The purpose of this study was to find a suitable model to evaluate the relationship between temperature and intracerebral hemorrhage (ICH) and explore the effects of cold spells and heat waves on the clinicopathological parameters of ICH patients. **Methods:** We conducted a retrospective study based on the ICH admission in the First Affiliated Hospital of Harbin Medical University from 2015 to 2020 ($N = 11\ 124$). The relationship between different seasons and the number of patients with ICH was explored. Poisson Akaike information criterion (AIC) was used to select the optimal model for temperature and ICH. Binary logistic regression analysis was used to investigate the association between extreme temperatures and clinicopathological features. **Results:** Hospital admissions for patients with ICH showed monthly changes. The optimal cold spell was defined as the daily average temperature < 3rd percentile, lasting for five days, while the optimal heat wave was defined as the daily average temperature >97th percentile, lasting for three days. Based on the generalized extreme weather model, cold climate significantly increased the risk of hematoma volume expansion (OR 1.003; 95% CI: 1.000-1.005, $P = 0.047$). In the optimal model, the occurrence of cold spells and heat waves increased the risk of midline shift in both conditions (OR 1.067; 95% CI: 1.021-1.115, $P = 0.004$; OR 1.077; 95% CI: 1.030-1.127, $P = 0.001$). **Conclusion:** Our study shows that seasonal cold spells and heat waves are essential factors affecting ICH severity, and targeted preventive measures should be taken to minimize the pathological impacts.

Keywords

ambient temperature; intracerebral hemorrhage; hematoma volume; midline shift

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1 Introduction

Stroke is one of the most common causes of death and disability. In 2019, there were 6.6 million deaths attributable to stroke worldwide^[1]. In recent years, stroke has become the leading cause of death in China, surpassing cancer and coronary heart disease^[2]. Intracerebral hemorrhage (ICH) accounts for about 26.7% of all stroke cases but causes 50.0% of mortality in China^[3], placing a high burden on the health system.

Environmental factors, including extreme temperature, are considered risk factors for stroke. According to the Global Burden of Disease Study (GBD) 2019, 6.6% of total stroke disability-adjusted life-years (DALYs) were attributable to low

or high ambient temperature^[4]. Several reports suggested associations between cold exposure and ICH incidence^[5-6] and mortality^[7-8]. However, very little research has been published on the relationship between high temperature and ICH occurrence. Moreover, few studies have addressed the association between clinicopathologic features of ICH and ambient temperature. Zheng *et al.* found no evident relationship between ambient temperature, clinical parameters, and hematoma volume in ICH^[9]. However, the sample size in this study is relatively small, and patients are geographically dispersed. A study with a larger sample and stronger regionality is needed.

Heilongjiang province is the northernmost province of China,

with a frigid climate and high mortality rate of stroke^[10]. In this study, we analyzed 11 124 admissions of ICH cases in the First Affiliated Hospital of Harbin Medical University from 2015 to 2020. We explored the effects of extreme temperatures on clinicopathologic parameters of ICH patients and the potential correlation with gender and age.

2 Methods

2.1 Study settings

Harbin, the capital city of Heilongjiang Province, is located in northeast China (between 125°42'-130°10' east longitude and 44°04'-46°40' north latitude), with a total population of 9 513 400 and an area of 53 100 square kilometers (National Bureau of Statistics, 2019, <http://data.stats.gov.cn/>). This region has a typical mid-temperate continental monsoon climate. Winter is long, cold, and dry from November to March and sometimes with heavy snow. In January, the average temperature was -15°C to -30°C, and the lowest temperature ever reached -37.7°C.

2.2 Study population

We conducted a retrospective study of patients with ICH admitted to the Stroke Department of the First Affiliated Hospital of Harbin Medical University between January 2015 and December 2020. ICH was diagnosed by neurosurgeons according to the international classification of diseases, 10th Revision (I61.0) criteria. Medical record of each ICH patient included demographical and clinical characteristics such as age, sex, admission date, hospital stay, previous disease history, and imaging data. Computed tomography was performed on each patient to confirm the diagnosis of ICH after admission. We excluded patients whose long-term residence was not in Harbin. A total of 11 124 patients with ICH were included in this study. The study protocol was approved by the Institutional Review Board of The First Affiliated Hospital of Harbin Medical University. Meanwhile, the study procedure complied with the relevant regulations and guidelines of Harbin Medical University.

2.3 Meteorological data

Daily meteorological data from 1st January 2015 to 31st December 2020 were obtained from the National Meteorological Information Center (<http://data.cma.cn/data/cdcindex/cid/f0fb4b55508804ca.html>). The data contained daily maximum temperature, daily minimum temperature, daily average temperature, wind speed, rainfall, and atmospheric pressure in Harbin. The missing values were labeled according to the data.

2.4 Definition of heatwaves and cold spells

Definitions of the cold spell and heatwaves vary from study to study. In some studies, cold spells and heatwaves are defined as increasing or decreasing temperature to a specific value that lasts for a period of time^[11-13]. However, given the different geographical locations and climatic conditions in which the study was conducted, it is more reasonable to use the percentile method to describe regional air temperature extremes^[11,14]. In addition, we adopted daily average temperature as a specific descriptive indicator of ambient temperature. Compared with daily maximum temperature and daily minimum temperature, daily average temperature can better reflect daily climate. Since there was no clear definition of cold spell and heatwaves in our region, cold spell in our study was defined as the daily average temperature <10th percentile (-16.3°C), and heatwave was defined as the daily average temperature >90th percentile (22.6°C)^[12,15-16]. Moreover, to identify a climatic model which produces an enormous effect on ICH, we examined 18 heatwaves and cold spell models with temperatures at the 97th, 95th, 90th, 10th, 5th, or 3rd percentile lasting for 2, 3, or 5 consecutive days during the study period in Harbin, as described in a previous study^[17].

2.5 Statistical analysis

Statistical analysis and calculations were carried out using dedicated software (IBM SPSS Statistics 21.0; SPSS Inc, Armonk, NY, USA). Categorized variables were expressed as counts (percentages) and were compared using the chi-square test or Fisher's exact test. Continuous variables were expressed as the mean ± SD or median (interquartile range [IQR], 95% confidence intervals [CI]) values. *T*-test and Mann-Whitney-Wilcoxon test were employed for normally distributed continuous variables and non-normally distributed continuous variables, respectively. Furthermore, we used the Poisson Akaike information criteria (AIC) to choose the optimal degrees of freedom.

Binary logistic regression analysis was used to analyze the association between extreme temperatures and statistically significant variables in intergroup comparisons. The odds ratio (OR) and the corresponding 95% *CI* were used to describe the data distribution. Statistical significance for all tests was defined as *P* < 0.05.

3 Result

A total number of 11 124 ICH patients were admitted to the Stroke Department of the First Affiliated Hospital of Harbin Medical University between 1st January 2015 and 31st

December 2020. Dramatic atmospheric temperature changes accompanied by an increase in the number of patients presenting with intracerebral hemorrhage were observed despite that only single-center data were recorded (Fig. S1-S6). Pearson correlation test revealed that the number of patients with ICH was significantly correlated with the temperature change ($P < 0.001$)^[7]. Table 1 shows the statistical data on the demographic characteristics of the patients included in this study. The majority of the patients were male (66.8%). The mean age of the patients was 58.28 ± 12.76 years, and more than half of the patients had or maintained smoking and drinking habits (50.1% and 50.3%). Most of the patients with ICH included in this study had a history of hypertension (67.9%), and 1 493 patients had a history of ischemic stroke before intracerebral hemorrhage. The mean systolic blood pressure (SBP) of all patients was 169.24 ± 31.13 mmHg, and the median value of hematoma volume was 13.55 mL (4.77-32.36).

The number and proportion of ICH patients and mean outdoor temperature per month are shown in Table 2. January had the lowest average temperature, and patients had the highest systolic blood pressure and the most massive average hematoma volume in the month. There was a significant increase in the number of individuals with ICH onset in the

Table 1 Demographic and clinical characteristics of ICH patients enrolled in the present study during the period from 2015 to 2020

Items	Total (N = 11 124)
Age, years	58.28 ± 12.76
Gender, N (%)	
Male	7 435 (66.8)
Female	3 689 (33.2)
Drinking, N (%)	5 310 (50.3)
Smoking, N (%)	5 293 (50.1)
History of diabetes, N (%)	1 258 (11.5)
History of hypertension, N (%)	7 432 (67.9)
History of ischemic stroke, N (%)	1 493 (13.6)
HLOS, days	9.00 (6.00-12.00) [‡]
Body temperature, °C	36.56 ± 0.43 [#]
Heart rate, beats per min	81.42 ± 17.81 [#]
SBP, mm Hg	169.24 ± 31.13 [#]
DBP, mm Hg	98.07 ± 18.99 [#]
Initial cerebral hemorrhage volume, mL	13.55 (4.77-32.36) [‡]
Midline shift, mm	2.49 (0-4.92) [‡]

SBP, systolic blood pressure; DBP, diastolic blood pressure; HLOS, hospital length of stay; ICH, intracerebral hemorrhage; IVH, intraventricular hemorrhage on presentation; [‡], values are median (interquartile range, IQR); [#], values are mean ± SD.

other three seasons compared to summer (June, July, and August), but the degree of midline shift was smaller. We conducted an analysis of meteorological data from 2015 to 2020 and stratification on the data collected from patients with ICH in cold climates and hot climates. At admission, the proportion of male patients in the cold spell group was higher than that in the control group (69.9% vs. 66.7%, $P = 0.038$), and fewer patients consumed alcohol and smoked (Drinking: 42.1% vs. 50%, $P < 0.001$; Smoking: 43.2% vs. 49.5%, $P < 0.001$; Table 3). The occurrence of diabetes mellitus, hypertension, and ischemic stroke was not significantly different between the two groups. In addition, there was no significant statistical difference in vital signs of body temperature, heart rate, and blood pressure between the two groups at admission. However, compared with the control group, the bleeding volume in the cold spell group was significantly increased (14.56 mL, IQR: 5.02-36.03 vs. 2.48 mL, IQR: 0-17.82, $P < 0.047$), but no significant difference was observed in hematoma location and the degree of midline shift.

Compared with the control group, more patients in the heatwave group continued their drinking and smoking habits (Drinking: 56.9% vs. 50%, $P < 0.001$; Smoking: 57.5% vs. 49.5%; $P < 0.001$), and systolic blood pressure at admission was significantly lower than that in the control group (166.76 ± 32.37 vs. 169.36 ± 30.79 g/L, $P = 0.019$). The imaging data showed no significant difference in hematoma volume and bleeding location between the two groups. However, the probability and degree of midline shift in the heatwave group were significantly higher than those in the control group ($P < 0.001$).

The results presented above indicate that the change of temperature has a significant influence on the occurrence and severity of ICH. We compared the overall performance of the 18 models to identify the best extreme climate-ICH model for Heilongjiang province. Table 4 presents nine cold spell models and nine heatwave models combining different intensities and frequencies. Apparently, while cold spell and heat wave are defined with a longer duration, the occurrence of extreme weather decreases. In cold spell models, only 21 cold spell days when the temperature dropped to below 3% for more than five days. Also, only 17 heat wave days were recorded in the heatwave model when the temperature stayed above 97% for more than five days. In addition, the AIC values of the two models were relatively smaller in the same group.

Next, we performed a univariate logistic regression analysis on patients' lifestyle, hemorrhage volume, and midline shifts on the generalized extreme weather model (model 1 and model 10). The findings indicated that cold spell significantly increased the risk of larger hematoma volume relative to the control group (OR 1.003; 95% CI : 1.000-1.005, $P = 0.047$). However, there

Table 2 Month-dependent changes of 6-year averaged values (from 2015 to 2020) of number, proportion, vital signs and imaging data in patients with ICH

Month	N	%	SBP, mm Hg [#]	DBP, mm Hg [#]	Initial cerebral hemorrhage volume, mL [†]	Midline shift, mm [†]	Mean temperature, °C [#]
Jan	998	9.0	172.39 ± 33.43	99.01 ± 19.17	26.38 (24.15-28.60)	2.34 (0-4.88)	-16.77 ± 4.64
Feb	898	8.1	170.59 ± 29.16	98.46 ± 18.43	23.41 (21.14-25.68)	2.05 (0-5.00)	-11.94 ± 6.11
Mar	1 023	9.2	169.02 ± 32.11	98.43 ± 19.12	24.89 (22.45-27.32)	2.37 (0-4.51)	-0.24 ± 6.74
Apr	956	8.6	171.77 ± 32.34	98.18 ± 18.83	26.31 (23.89-28.72)	3.10 (0-4.83)	8.40 ± 5.46
May	920	8.3	169.98 ± 30.43	97.32 ± 18.36	25.33 (22.80-27.85)	2.85 (0-5.17)	15.40 ± 4.67
Jun	767	6.9	168.84 ± 30.78	97.46 ± 17.75	24.08 (21.45-26.71)	2.56 (0-5.12)	20.33 ± 2.99
Jul	734	6.6	166.51 ± 32.02	98.78 ± 22.19	25.95 (22.78-29.12)	3.57 (1.90-5.72)	23.83 ± 2.64
Aug	798	7.2	165.45 ± 30.73	99.26 ± 22.67	25.07 (21.99-28.15)	3.00 (0.69-4.85)	21.61 ± 2.89
Sep	953	8.6	168.05 ± 29.13	98.37 ± 18.19	22.61 (19.58-25.64)	2.41 (0-4.41)	16.00 ± 3.84
Oct	1 125	10.1	167.99 ± 30.68	97.16 ± 17.69	24.43 (21.92-26.94)	3.06 (0-5.41)	6.32 ± 4.64
Nov	980	8.8	169.60 ± 30.32	97.59 ± 18.18	24.56 (21.80-27.32)	0 (0-4.90)	-6.05 ± 6.11
Dec	892	8.0	168.05 ± 31.14	96.79 ± 18.13	25.08 (22.41-27.74)	0 (0-4.32)	-14.66 ± 5.54
Lost	80	0.7					

ICH, intracerebral hemorrhage; SBP, systolic blood pressure; DBP, diastolic blood pressure; [†], values are median (interquartile range, IQR); [#], values are mean ± SD.

Table 3 Comparison of the baseline demographic and clinical characteristics of patients with ICH stratified by heat wave or cold spell.

Group	Age, y [#]	Sex (male), N (%)	Drinking, N (%)	Smoking, N (%)	History of Diabetes, N (%)	
Control group (N = 8 752)	58.33 ± 12.579	5 837 (66.7)	4 179 (50.0)	4 140 (49.5)	992 (11.5)	
Cold-spell group (N = 1 030)	58.24 ± 12.931	720 (69.9) [†]	409 (42.1) ^{†††}	421 (43.2) ^{†††}	117 (11.6)	
Hot-wave group (N = 992)	58.16 ± 13.560	647 (65.2)	520 (56.9) ^{†††}	526 (57.5) ^{†††}	116 (11.9)	
Group	History of Hypertension, N (%)	History of Ischemic stroke, N (%)	SBP, mm Hg [#]	DBP, mm Hg [#]	Heart Rate, beats per min [#]	
Control group (N = 8 752)	5 872 (68.1)	1 182 (13.7)	169.36 ± 30.787	97.94 ± 18.638	81.33 ± 17.818	
Cold-spell group (N = 1 030)	637 (63.2) ^{††}	141 (13.9)	170.67 ± 32.988	98.23 ± 18.752	81.53 ± 18.300	
Hot-wave group (N = 992)	681 (70.2)	126 (12.9)	166.76 ± 32.366 [†]	98.59 ± 22.175	81.67 ± 17.375	
Group	Body Temperature, °C	Initial hematoma volume, mL ^{##}	Location, N (%)			
			Lobar	Deep	IVH	Infratentorial
Control group (N = 8 752)	36.59 ± 0.42	2.48 (0-17.816)	982 (18.4)	3 762 (70.5)	158 (3.0)	437 (8.2)
Cold-spell group (N = 1 030)	36.58 ± 0.45	14.56 (5.020-36.030) [†]	149 (19.9)	501 (66.9)	22 (2.9)	77 (10.3)
Hot-wave group (N = 992)	36.60 ± 0.42	13.4921 (4.267-32.719)	105 (17.1)	436 (71.1)	18 (2.9)	54 (8.8)
Group	Midline shift binary, N (%)	Midline shift, mm ^{###}	Mean temperature, °C ^{###}	Surgery, N (%)		
Control group (N = 8 752)	2 589 (64.4)	2.52 (0-4.840)	6.20 (-5.20-15.60)	2 047 (23.4)		
Cold-spell group (N = 1 030)	327 (67.4)	2.64 (0-5.354)	-19.00 (-20.90--17.60) ^{†††}	236 (23.0)		
Hot-wave group (N = 992)	360 (81.1) ^{†††}	3.3155 (1.551-5.520) ^{†††}	24.9000 (23.70-26.30) ^{†††}	243 (24.5)		

SBP, systolic blood pressure; DBP, diastolic blood pressure; ICH, intracerebral hemorrhage; IVH, intraventricular hemorrhage on presentation; [†], P < 0.05 (vs. control.); ^{††}, P < 0.01 (vs. control.); ^{†††}, P < 0.001 (vs. control.); [#], values are mean ± SD; ^{##}, values are median (interquartile range, IQR).

Table 4 Cold spell days and heat-wave days discovered by different intensities and frequencies

Models	Definition	Number of days	N	AIC value
1	< 10th percentile with ≥ 2 days duration	200	1030	1772.168
2	< 10th percentile with ≥ 3 days duration	167	843	1546.364
3	< 10th percentile with ≥ 5 days duration	118	576	1136.208
4	< 5th percentile with ≥ 2 days duration	98	485	698.945
5	< 5th percentile with ≥ 3 days duration	76	382	603.058
6	< 5th percentile with ≥ 5 days duration	29	138	269.518
7	< 3rd percentile with ≥ 2 days duration	57	285	429.656
8	< 3rd percentile with ≥ 3 days duration	49	235	363.799
9	< 3rd percentile with ≥ 5 days duration	21	104	198.704
10	> 90th percentile with ≥ 2 days duration	256	992	898.831
11	> 90th percentile with ≥ 3 days duration	244	938	834.535
12	> 90th percentile with ≥ 5 days duration	191	766	639.896
13	> 95th percentile with ≥ 2 days duration	131	487	177.928
14	> 95th percentile with ≥ 3 days duration	108	417	172.234
15	> 95th percentile with ≥ 5 days duration	67	272	115.869
16	> 97th percentile with ≥ 2 days duration	78	284	24.453
17	> 97th percentile with ≥ 3 days duration	48	193	0.421
18	> 97th percentile with ≥ 5 days duration	17	63	25.945

Dependent variable: average temperature; Independent variables: onset month, alcohol consumption, smoking, length of hospital stay, systolic blood pressure, history of hypertension, intracerebral hemorrhage volume, midline displacement.

was no significant association in the heatwave group. The degree of midline shift was more severe with the occurrence of heat wave (OR 2.369; 95% CI : 1.852-3.030, P = 0.001). In addition, temperature changes had a noticeable effect on patients' habits of (Table 5). We performed a univariate logistic regression analysis again based on the optimal model. The results showed that the occurrence of cold spells and heat waves had a significant impact on the severity of ICH, and the risk of midline shift was significantly increased in both groups (OR 1.067; 95% CI : 1.021-1.115, P = 0.004; OR 1.077; 95% CI : 1.030-1.127, P = 0.001).

4 Discussion

In the present retrospective study, we included 11 124 patients with ICH in a regional center hospital in Heilongjiang province over a 6-year period. This study is the first to explore the association between ambient temperature and ICH in the cold region of northeast China. We also innovatively studied the relationship between pathological parameters such as midline shift or hematoma volume of ICH and cold spell or heat wave, which inspired the further exploration of the

pathological mechanism of temperature's influence on ICH and provided a theoretical basis for preventive measures of ICH in cold regions.

In the present study, we analyzed the data information of patients with ICH in cold climates and hot climates. Consistent with other studies, our analysis showed that men are more likely to have ICH during cold spells^[18-19], which may correlate with more outdoor activity of men in winter. Interestingly, we found significantly lower smoking and alcohol consumption rates in the cold wave group than in the control group but significantly higher rates in the heat wave group, which has not been previously reported. The findings suggest that tobacco and alcohol might have certain protective effects on cold-induced ICH, which needs to be verified by more rigorous and specially designed studies.

In addition, by selecting appropriate cold spell and heat wave models, we found a significant association between temperature change and the incidence and severity of ICH. Several studies have found that low temperature significantly affects ICH admission in China and in other countries as well. One research conducted in Beijing between 2013 and

Table 5 Predicted effects of cold wave and heat wave on blood pressure, bleeding volume, midline shift and other related variables in the Logistic regression

Logistic regression	Sex (male)	Drinking	Smoking	SBP	Initial hemato- ma volume	Midline shift binary	Midline shift	
Model 1	OR (95% CI)	1.160 (1.008-1.335)	0.727 (0.636-0.832)	0.776 (0.679-0.887)	1.001 (0.999-1.003)	1.003 (1.000-1.005)	1.144 (0.936 -1.398)	1.002 (0.980 -1.023)
	P value	0.038	<0.001	<0.001	0.214	0.047	0.189	0.879
Model 9	OR (95% CI)	0.667 (0.427-1.043)	0.132 (0.072-0.241)	0.201 (0.120-0.340)	1.001 (0.994-1.007)	1.002 (0.994-1.009)	2.625 (1.525-4.519)	1.067 (1.021-1.115)
	P value	0.076	<0.001	<0.001	0.814	0.671	<0.001	0.004
Model 10	OR (95% CI)	0.937 (0.816-1.075)	1.321 (1.151-1.156)	1.378 (1.200-1.582)	0.997 (0.995-1.000)	1.002 (0.999-1.005)	1.058 (1.035-1.082)	2.369 (1.852-3.030)
	P value	0.352	<0.001	<0.001	0.019	0.292	<0.001	0.001
Model 17	OR (95% CI)	0.961 (0.711-1.298)	1.289 (0.947-1.755)	1.247 (0.918-1.694)	1.002 (0.997-1.006)	0.998 (0.990 -1.005)	3.618 (1.912-6.846)	1.077 (1.030-1.127)
	P value	0.795	0.107	0.157	0.516	0.578	<0.001	0.001

SBP, systolic blood pressure.

2014 showed that extreme cold temperature (first percentile of temperature) is associated with increasing hemorrhagic stroke admissions^[19]. Similar conclusions were reached in the studies conducted in Nanchang^[20], Jinan^[21], and Guangzhou^[22]. The mortality of ICH has also been shown to increase with temperature reduction^[7-8]. However, few studies investigate the effects of temperature on clinical-pathological parameters of ICH. Cold exposure may induce peripheral vasoconstriction and consequently elevates blood pressure and increases cerebral blood flow^[23-24]. Moreover, low temperature inhibits the activation of the coagulation system^[25]. These facts explain why the bleeding volume in the cold spell group was significantly increased. However, an analysis from INTERACT1 indicates no appreciable association of temperature parameters with clinical severity nor with hematoma volume^[9]. The discrepancy could be explained by the difference in sample size and regional distribution of patients in different studies.

Whether heat wave affects ICH remains controversial among researchers. For example, Takumi *et al.* found a significant increase in hospital admissions for ICH for every 1°C increase in maximum temperature^[26]. Another study in Nanchang, China showed that exposure to extremely high temperatures within three days before the onset of the condition was associated with an increased risk of admission with ICH^[20]. A pooled analysis of four studies reported a statistically significant association between increased mean ambient temperature and ICH incidence, OR 0.97(0.94-1.00)^[27]. In contrast, a study in Shenzhen, China revealed the protective effect of short-term high temperature on the onset of ICH^[28]. In our research, the probability and degree of midline shift in the heatwave group were significantly higher than those in the control group. Considering that there are few absolute high-temperature days

in this region, whether the observed phenomenon is merely a random coincidence or a true connection with underlying mechanisms needs to be clarified in future studies.

One of the strengths of the present study is the large sample size. Another advantage is that our data were collected from a large medical center and have high levels of standard and representativeness. Nonetheless, our study also has some limitations. First, this is a single-center study with a single source of data acquisition, and the increase in hospital admissions was perceived as the increase in disease incidence. Second, the present study did not evaluate the effects of air pollution which has been demonstrated to be associated with the incidence of ICH^[29]. Third, the impact of living environment and conditions, such as indoor heating, on cerebral hemorrhage was not included in experimental design. Moreover, it has been suggested that the suburban residents with lower socioeconomic levels are more vulnerable to the effects of heat and cold on stroke hospitalization^[30]. Furthermore, the lag effects of extreme climate were not integrated into the analyses.

5 Conclusion

Our study findings indicate that seasonal cold spells and heat waves are essential factors affecting the severity of cerebral hemorrhage. There is a higher risk of intracerebral hemorrhage and larger hemorrhage volumes during cold spells in Heilongjiang province, whereas shifts in midline structures are more likely to occur during heatwaves. In addition, the severity and duration of extreme climate can amplify the impact. The best cold spell and heatwave models in Heilongjiang province were defined as the daily average temperature below (or above)

the 3rd percentile lasting for more than five days. When extreme weather occurs, targeted preventive measures should be actively taken for people with hypertension and a history of stroke.

Conflicts of interests

The authors report no conflicts of interests in this work.

Consent for publication

The need for informed consent was waived due to the retrospective nature of the study. The manuscript does not contain identifying details.

Ethical approval

The study protocol was approved by the Institutional Review Board of The First Affiliated Hospital of Harbin Medical University. Simultaneously, all methods were carried out following the relevant regulations and guidelines of Harbin Medical University. And has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. The need for informed consent was waived by the Institutional Review Board of The First Affiliated Hospital of Harbin Medical

University due to the retrospective nature of the study.

Author contributions

Chunyang Liu, Xun Xu and Guang Yang did the work of concept and design. Chunyang Liu, Xun Xu, Rui Liu and Guang Yang did the writing of the manuscript. Chunyang Liu, Qiuyi Jiang, Enzhou Lu, Chao Yuan, Yanchao Liang, Huan Xiang and Xun Xu did the data collection. Boxian Zhao, Xin Chen and Guang Yang did the critical revision for important intellectual content.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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