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Study on the relationship among typhoon, weather change and acute ischemic stroke in southern Zhejiang Province of China

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Abstract

Objective This study aimed to investigate the relationship between the unique weather change and acute ischemic stroke (AIS) in the southern Zhejiang Province of China and to provide evidence for better predicting and preventing stroke.

Methods We retrospectively collected 14,996 ischemic stroke patients data and weather data from January 2019 to December 2021 in the southern Zhejiang Province of China. The correlation and risk between meteorological factors and the number of AIS daily cases were calculated. Wilcoxon rank sum test was used to calculate the difference in the number of cases between typhoon-affected and non-affected periods. A prediction model obeying Poisson regression was established, and the accuracy of the correlation factors in predicting the number of cases was verified.

Results In southern Zhejiang Province, the number of AIS was the highest in summer and the lowest in spring. Stroke onset is associated with temperature, water vapor pressure and typhoons ($P<0.05$). The presence of typhoon (RR 0.882; 95% CI 0.834 to 0.933, $P<0.001$) was a protective factor, while maximum temperature (RR 1.021; 95% CI 1.008 to 1.033, $P=0.043$) and the water vapor pressure (RR 1.036; 95% CI 1.006 to 1.067, $P=0.036$) were risk factors. The occurrence under the influence of typhoons was lower than that without the influence of typhoons ($P<0.05$). The prediction model can predict the occurrence of stroke.

Conclusion An association was observed between the occurrence of AIS, temperature, water vapor pressure and typhoon in the southern Zhejiang Province of China. Typhoon occurrence was associated with fewer cases. The predictive model may help high-risk populations prevent diseases early and assist hospitals in allocating resources promptly.

Keywords Acute ischemic stroke, Typhoon, Weather, Meteorological condition, Occurrence

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Introduction

Stroke often leads to death and disability. Acute ischemic stroke (AIS), the most common type of stroke, is an acute brain cell injury caused by reduced blood flow to the brain. Clinical symptoms include sudden limb numbness, slurred speech, unconsciousness, or even loss of life in severe cases [1]. A series of global burden of disease studies revealed that despite the global age-standardized mortality rates of stroke had declined since 1990, about 5.5 million people still died from stroke in 2016 [2]. Cerebrovascular accident is the third leading cause in China, according to the survey, in 2019, there were 39,400 new stroke cases and 21,900 stroke deaths in China [3]. In the context of high mortality and high disability of stroke, how to prevent and what factors may play a protective role have become a major research direction of stroke.

In recent years, in addition to traditional factors such as hypertension, heart disease, diabetes, smoking and obesity [4, 5], researches have shown that weather is also associated with stroke onset [6–10]. However, whether different meteorological parameters increase or decrease the incidence of stroke is still controversial [11]. In addition, due to the differences in characteristic climate types and meteorological conditions in different countries and regions, the seasonal changes of stroke incidence in different studies are also different [12–14].

Southern Zhejiang Province of China has its unique seasonal change time, which is earlier than the national average. It is generally believed that in southern Zhejiang Province, spring occurs from February to April, summer occurs from May to July, autumn occurs from August to October, and winter occurs from November to January. The unique seasonal division may influence the result of seasonal variation of stroke incidence, which may be different from the results of studies in other regions.

Located in the subtropical monsoon climate belt, the south of Zhejiang Province is mild and dry in winter and hot and rainy in summer. Typhoons occur frequently in summer and autumn in southern Zhejiang, especially Wenzhou city and Taizhou city. In recent 70 years, as many as 23 typhoons landed in Wenzhou, 19 typhoons landed in Taizhou, and countless typhoons passed through and affected this area. Under the influence of typhoons, meteorological conditions such as wind speed, daily rainfall, humidity, temperature and atmospheric pressure change uniquely in southern Zhejiang Province, which may be related to stroke. There are few previous articles on the impact of typhoons or tropical cyclones on stroke, and only two studies have explored the impact of hurricanes on stroke incidence in the United States [15, 16]. Both studies found that hurricanes may be associated with local changes in stroke incidence, suggesting the feasibility of research on typhoons.

The purpose of this study was to investigate the relationship between weather change, typhoon and AIS in southern Zhejiang Province of China, to warn the high-risk population before the relative weather and seasonal changes, and to help staff coordinate hospital resources in time.

Materials and methods

Clinical data

The clinical data of emergency patients with ischemic stroke from three hospitals in southern Zhejiang Province from January 2019 to December 2021 were retrospectively collected. Raw data was collected using the International Classification of Diseases, Tenth Revision (ICD-10) diagnostic code I63.x [17] through the electronic medical record system. Then manual screening was performed to exclude patients without ischemic stroke confirmed by CT imaging and patients who were admitted to the emergency but actually did not have an acute disease through the collected clinical information (admission time, ancillary tests, medical history, etc.). The daily number of AIS was summarized lastly. Our study did not collect the patients' names, and only counted the daily number of AIS to conduct relevant research, fully protecting the privacy of patients.

Inclusion criteria for this study: (1) patients with ischemic stroke; (2) emergency patients; (3) the cases occurred in southern Zhejiang Province. (4) CT imaging confirmed ischemic stroke. Exclusion criteria: (1) non-emergency patient or chronic stroke; (2) patients with hemorrhagic stroke; (3) patients admitted for stroke sequelae; (4) cases with onset outside the three areas; (5) cases with unclear time of onset or lack of clinical information.

Meteorological data

Daily meteorological data and typhoon information from 2019 to 2021 in the south of Zhejiang were collected at Wenzhou Station (district station No. 58659, longitude 120°39' 00", latitude 28°02' 00", altitude 28.3 m), and exported from the meteorological data system by a researcher of the Meteorological Bureau. The data covered all southern Zhejiang Province.

Statistical analysis

Statistical analysis was performed with SPSS 25.0, Stata version 17 and R 4.2.2. SPSS was used to describe the distribution of AIS for different seasons and months. Variance Inflation Factor (VIF) was calculated before Poisson regression to eliminate the multicollinearity among independent variables (if VIF>10, collinearity exists). The relevant factors were first screened using univariate Poisson regression, and the selected factors were subjected to multivariate Poisson regression by Stata to analyze

the correlation and risk of these meteorological factors with the number of stroke cases. A generalized additive model (GAM) with smoothed splines obeying the Poisson distribution was fitted to visualize stroke-related weather factors. To assess the Poisson regression model, Omnibus test, fitting tests of predicted and actual values were performed. Weather data in 2022 was collected and imported it into the model for external verification.

Two weeks after typhoon landing day was taken as the "Affected interval" because one study about hurricanes and strokes found that hurricanes had an effect on stroke rates in the two weeks after a hurricane [15]. To ensure the consistency of the control time variables, one week before and one week after the "Affected interval" were taken as the "Interval not affected" by the typhoon. The number of cases within the "Affected interval" and "Interval not affected" was counted and compared using Wilcoxon rank sum test analysis.

All P values were 2-sided and statistical significance was defined as $P<0.05$.

Results

Descriptive data of stroke and meteorological variables

The final 14,996 patients were included in this study. Among these patients, 4104 had AIS occurring most in the summer, as compared with 3470 in spring, 3721 in autumn, and 3701 in winter. The cases of AIS in each season was significantly different ($P<0.05$). The highest incidence was in June with 1403 records; followed by July with 1391 records. Histograms of AIS cases for different months and seasons are shown in Fig. 1. Daily weather variables are described in Table 1.

Relationship between typhoon and stroke

The line graph (Fig. 2) shows the trend in the number of cases per month, with the red vertical line indicating months with typhoon impacts. There is a downward trend in the number of cases in months with typhoon landfall, suggesting that stroke occurrence may be related to typhoons.

To further clarify whether typhoons affect the occurrence of ischemic stroke, we compared the number of incidence cases between typhoon-affected and non-affected intervals by the Wilcoxon rank sum test. Set the typhoon influence time as two weeks after the landfall, and the rest as no typhoon influence time. Information regarding the typhoons that occurred in southern Zhejiang from 2019 to 2021, the number of cases affected by typhoons, and the number of cases that were not affected by typhoons are all summarized in Table 2. Compared with the interval not affected, the number of ischemic strokes decreased significantly in the affected interval($P<0.05$).

Description of the relationship between meteorology and stroke

Independent variables with VIF value much larger than 10 were deleted in the preliminary screening, including Tmean, Tmin, Pmax and Pmin. The remaining variables were entered into Poisson regression for further screening. The results of univariate Poisson regression showed that maximum air temperature (RR 1.007; 95% CI 1.005–1.010), mean atmospheric pressure(RR 0.995; 95% CI 0.993–0.997), water vapor pressure (RR 1.006; 95% CI 1.004–1.008), maximum wind speed (RR 0.974; 95% CI 0.950–0.998), sunshine duration (RR 1.004; 95% CI 0.999–1.010), and typhoon occurrence (RR 0.967; 95% CI 0.923–1.014) might be significant predictors ($P<0.1$). Precipitation ($P=0.388$), mean wind speed ($P=0.943$), extreme wind speed ($P=0.611$), mean humidity ($P=0.217$), and minimum humidity ($P=0.814$) had no significant effect on ischemic stroke.

Screened factors were included in multifactorial Poisson regression to analyze their association with acute ischemic stroke. The presence of typhoon (RR 0.882; 95% CI 0.834 to 0.933, $P<0.001$) was a protective factor, while the maximum temperature (RR 1.021; 95% CI 1.008 to 1.033, $P=0.043$) and the water vapor pressure (RR 1.036; 95% CI 1.006 to 1.067, $P=0.036$) were dangerous factors (Fig. 3). The atmospheric pressure, sunshine duration, maximum wind speed, mean air temperature and minimum air temperature were not statistically significant($P\geq0.05$).

The GAM model fitted with Poisson regression visually showed the relationship between maximum air temperature, vapor pressure and the number of cases (Fig. 4). As can be seen from Fig. 4a, in the general trend, the higher the temperature, the more the daily cases of AIS, but the trend is non-linear, too high or too low temperature will increase the number of strokes. Figure 4b shows that an increase in vapor pressure increases the number of strokes.

Validation of Poisson regression model

To verify the plausibility of the model, some tests were performed. The result of Omnibus test was the likelihood ratio chi square($\chi2$)=66.58, $P<0.001$, indicating that the data given were suitable to fit the corresponding Poisson regression model and the model was statistically significant. A time series prediction model with a Poisson distribution is also built. The expected number of cases matches the actual number, which verifies the reasonableness of the model (Fig. 5). We collected of weather data in 2022 and imported it into the model for external verification. Scatter plots of predicted and actual values show $R^2=0.509$, with a moderate model fit (Supplementary Fig. 1). The fit of the model may not be particularly

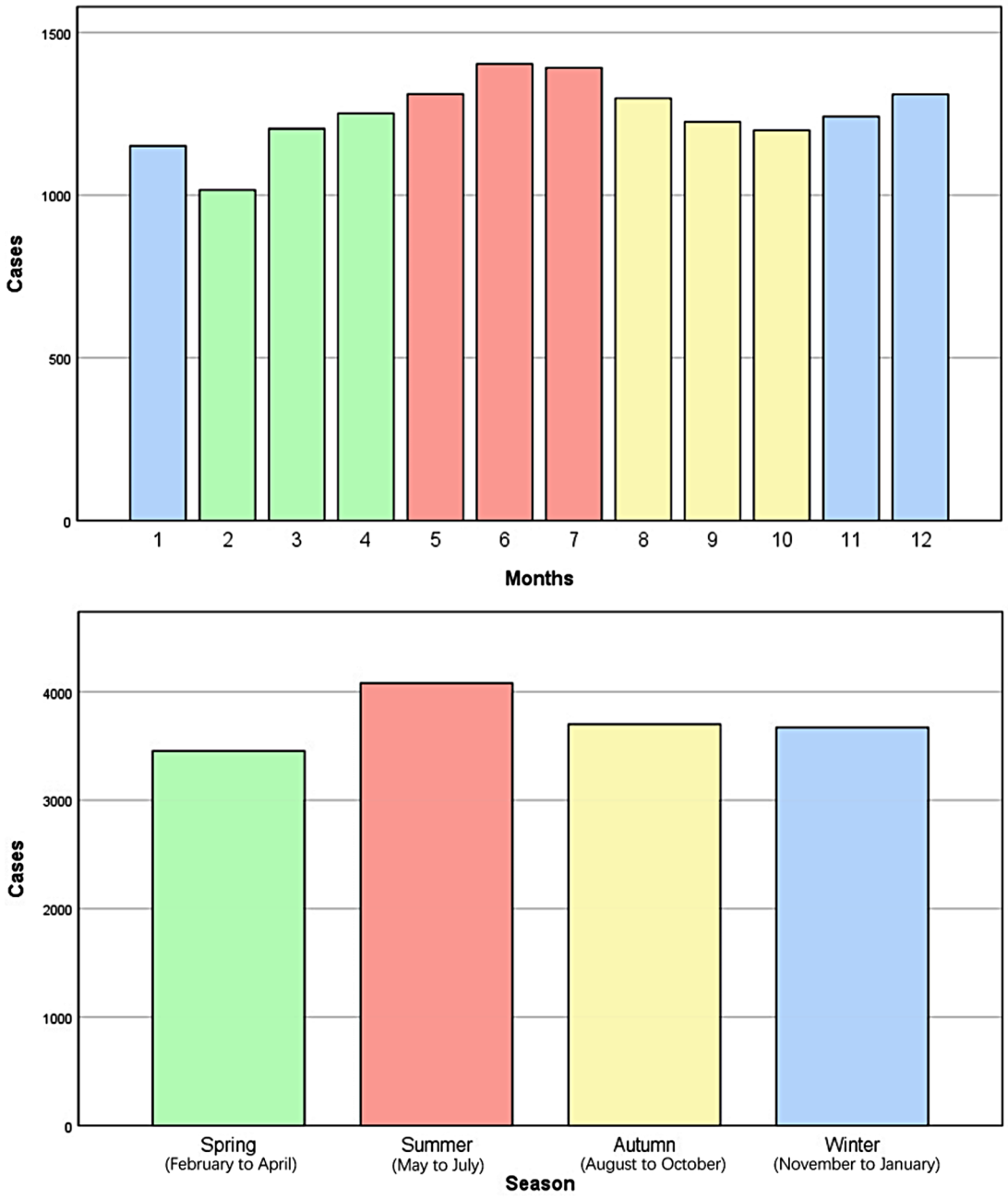

Fig. 1 Distribution of the number of acute ischemic stroke cases. (**a**) The number of cases in different months. (**b**) The number of cases in different seasons

excellent due to the limitations of retrospective studies and the influence of non-meteorological factors.

Discussion

It is found that ischemic stroke onset in southern Zhejiang Province had a peak in summer and a trough in spring. The onset of stroke in southern Zhejiang is related to meteorological factors, including temperature, wing speed, water vapor pressure and typhoons.

Effect of temperature on stroke

Most investigations on the association between weather and stroke onset have focused on temperature [18–23]. Our Poisson regression results showed that the number of ischemic stroke increased with temperature increase. Studies in different climates, including Italy [24], western Scotland [25] and Israel [26], have also shown that high temperature is an important cause of ischemic stroke. First of all, the main way of heat dissipation in the human body in a high-temperature environment is sweating. The lost water in the blood results in increased blood

Table 1 Description of daily weather variables

	Mean, per day	Std. Deviation	Minimum	Maximum
Cases	13.68	4.44	2	31
Precipitation, mm	5.28	13.85	0.00	238.50
Tmean,℃	19.78	7.14	1.90	32.30
Tmax,℃	24.30	7.63	6.00	40.00
Tmin,℃	16.96	7.13	-2.00	28.20
WSmean, m/s	0.79	0.35	0.00	2.10
WSmax, m/s	2.28	0.65	0.50	6.70
WSextreme, m/s	5.20	1.54	1.90	14.30
Hmean,%	76.64	12.59	32.00	100.00
Hmin,%	54.71	16.91	11.00	97.00
Sunshine, h	3.27	3.13	0.00	9.70
Pmean, hPa	1012.47	8.44	977.40	1032.40
Pmax, hPa	1014.81	8.59	985.80	1034.50
Pmin, hPa	1009.99	8.36	965.50	1029.90
Pvapor, hPa	19.40	9.14	2.10	35.60

Note: Tmean: mean air temperature. Tmax: maximum air temperature. Tmin: minimum air temperature. WSmean: mean wind speed. WSmax: maximum wind speed. WSextreme: extreme wind speed. Hmean: mean humidity. Hmin: minimum humidity. Sunshine: sunshine duration. Pmean: mean atmospheric pressure. Pmax: maximum atmospheric pressure. Pmin: minimum atmospheric pressure. Pvapor: water vapor pressure

Table 2 Incidence of stroke in typhoon affected and non-affected intervals

Start and end date	Name of typhoon	Incidence of ischemic stroke in interval 1	Incidence of ischemic stroke in interval 2
2019.08.08-2019.08.11	Lekima	155	167
2019.09.05-2019.09.06	Lingling	161	169
2019.09.21-2019.09.22	Tapah	151	165
2019.10.01	Mitag	157	145
2020.08.03-2020.08.04	HAGUPIT	214	220
2020.08.30-2020.09.01	Maysak	205	231
2021.07.24-2021.07.26	In-Fa	207	247
2021.08.07	LUPIT	202	217
2021.08.21-2021.08.23	OMAIS	185	200
2021.09.12-2021.09.13	CHANTHU	198	204
	SUM:	1835	1965
		z	*P* value
		-2.349	0.019*

Note: * Wilcoxon rank sum test, $P<0.05$. Interval 1: 2 weeks after typhoon landing in southern Zhejiang were taken as the affected interval. Interval 2: 1 week before and 1 week after the affected interval were taken as the interval not affected by typhoon

viscosity and increases possibility of ischemic stroke caused by thrombosis. Second, indoor air conditioning is very common in summer, and the temperature difference between indoors and outdoors is too large. Rapid temperature changes lead to sharp fluctuations in blood pressure and may induce stroke. In addition, psychology believes that the high heat and high humidity environment puts the human body in an "irritable state" and may even increase the incidence of mental illness [27–29]. Intense mood swings are also a possible reason for the increased incidence of stroke in summer.

Our visual GAM further suggests that an increase in temperature is correlated with increase in ischemic stroke, but the number of ischemic stroke also increases when the temperature is below 10 °C. Cold weather causes blood vessels to constrict through the sympathetic nervous system and the renin angiotensin system, which in turn raises blood pressure [30]. Second, cold weather

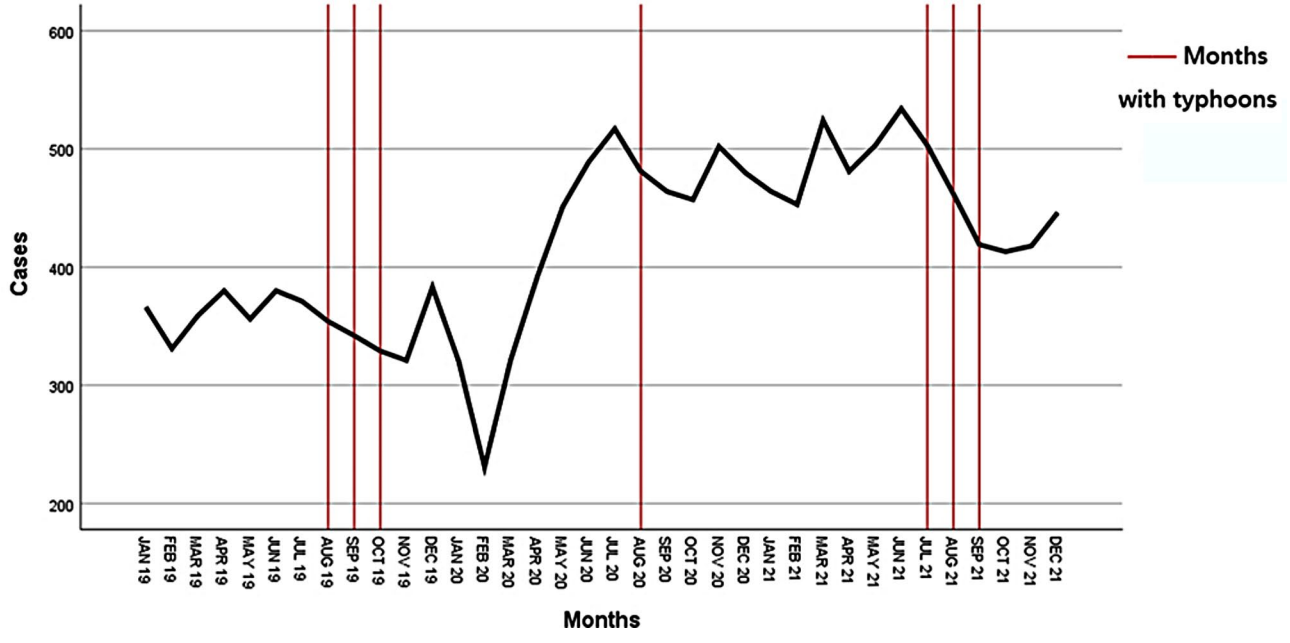

Fig. 2 The line chart of acute ischemic stroke cases per month with the month of typhoon occurrence marked

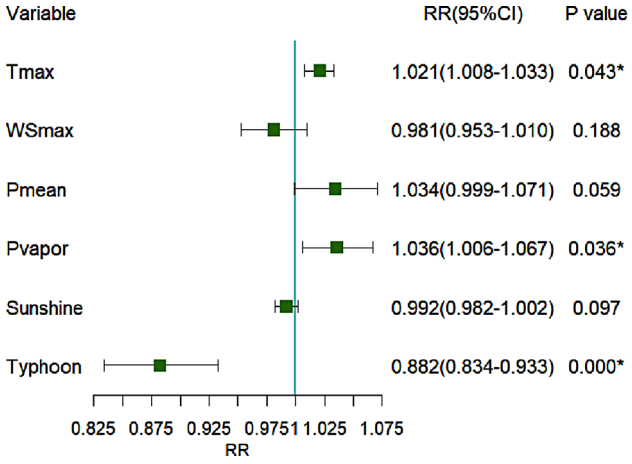

Fig. 3 Forest plot of factors analyzed for association with ischemic stroke. Note: Tmax: maximum air temperature. WSmax: maximum wind speed. Pmean: mean atmospheric pressure. Pvapor: water vapor pressure. *$P < 0.05$

affects the body's metabolism, and people are more likely to consume more high-calorie foods and exercise less, which raises blood pressure and blood lipids [31]. Thirdly, some studies have found that in cold weather, risk factors for arterial thrombosis such as red blood cell count, plasma cholesterol and fibrinogen increase, providing a basis for the increased incidence of ischemic stroke [32–34].

However, RR values showed a weak correlation between temperature and ischemic stroke. Southern Zhejiang is mostly a coastal city with a mild climate, not to mention a developed economy in Zhejiang Province and the popularity of air conditioning, which may lead to the weakening of the influence of temperature on the onset of stroke.

Effect of water vapor pressure on stroke

Water vapor pressure is the partial pressure of water vapor in atmospheric pressure. At the same temperature, the higher the partial pressure of water vapor, the more moisture it contains; At the same humidity, the higher the temperature, the higher the water vapor pressure. The hot and rainy summer in Zhejiang Province, with high temperature and high air humidity, causes the human body to sweat excessively, increasing blood viscosity, which can induce narrowing or blockage of blood vessels and, in severe cases, stroke. Similar to our results, a 12-year study from western Paris identified relative humidity as a risk factor for stroke occurrence [35].

Effect of typhoons on stroke

The main innovation of this study is the investigation of typhoons on the occurrence of ischemic stroke. There are few studies on the impact of typhoons on stroke, and only two studies have assessed the association between hurricanes or tropical storms and ischemic stroke in the United States [15, 16]. They found that hurricanes had an effect on stroke rates in the two weeks after a hurricane [15]. Therefore, we took the two weeks after the typhoon as the affected interval.

Our study found a significant reduction in the number of stroke cases in the interval affected by typhoons compared to the interval not affected. This is inconsistent with the previous two researches, and the reasons may be as follows. First, Joel N. Swerdel et al. [15] did not classify stroke, and the calculated data included hemorrhagic stroke and ischemic stroke, which may lead to different results from ours. Secondly, under the influence of hurricanes, the risk of car accidents and falling objects may be increased, making traumatic ischemic stroke more likely to occur. The two previous studies were conducted in areas that may not have as much experience dealing with

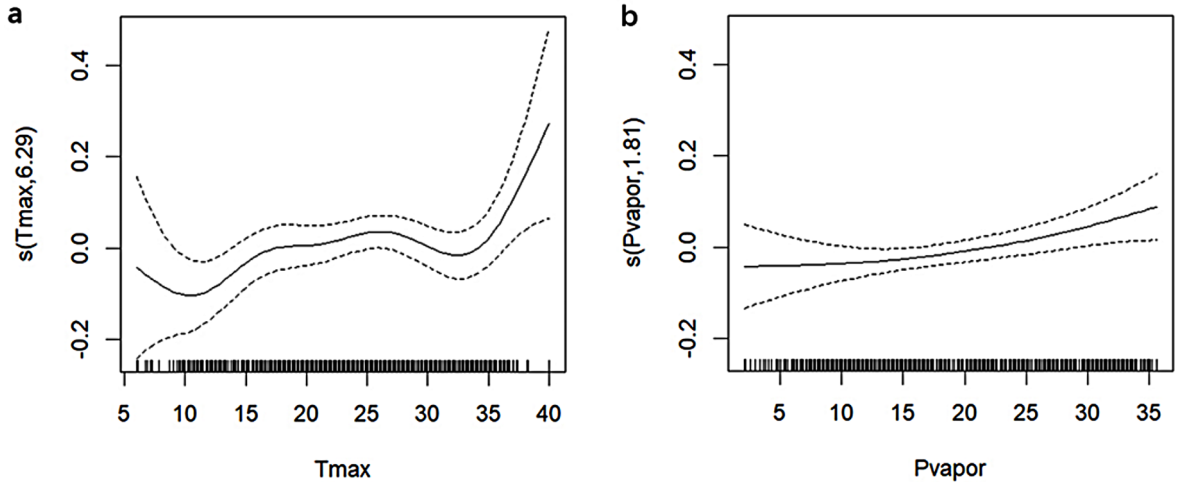

Fig. 4 Effect of different weather variables on stroke cases. (**a**) Effect of temperature on stroke cases. (**b**) Effect of vapor pressure on stroke cases

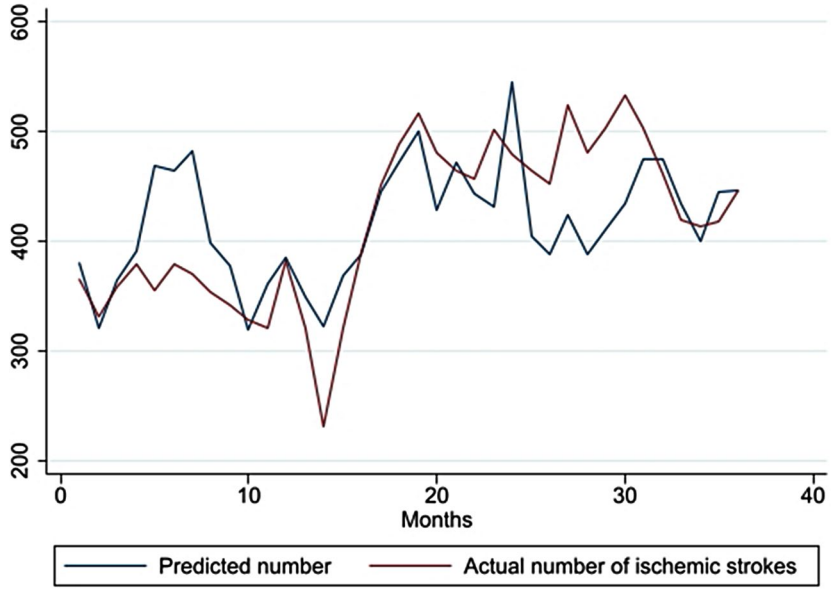

Fig. 5 The fitting of the predicted value based on the Poisson model to the actual number of cases

typhoons as we do, increasing in the number of strokes caused by typhoons. Typhoons are frequent in summer and autumn in the southern Zhejiang Province of China, so that relevant departments have early warnings and residents have a strong awareness of prevention. If severe typhoons are forecast, schools and offices will be closed, and residents can stay at home. All these may have contributed to the decline in the onset of traumatic ischemic stroke in southern Zhejiang Province of China.

In typhoon weather, wind speed, pressure, rainfall and temperature all fluctuate rapidly. It is difficult to say exactly what factors contribute to the protective effect of typhoons on AIS. As a low-pressure cyclone, typhoons may affect the occurrence of AIS through the change of pressure. Transmural pressure refers to the difference between the pressure of the blood in the vessel and the external tissue against the wall of the tube. When the external pressure is low, the transmural pressure of blood vessels increases and the blood vessels dilate, which may reduce the occurrence of stroke. Vladimir N Melnikov et al. confirmed that the enhanced air pressure would reduce arterial wall distensibility, compared the sensitivity of arteries in different parts to changes in air pressure, and found that the cerebrovascular system was most susceptible to changes in air pressure [36]. Moreover, low pressure may reduce the concentration of oxygen in human blood gases. Under hypobaric hypoxia, red blood cells, hemoglobin, hematocrit increase, and platelets activate [37]. These physiological changes are closely related to the increase of blood viscosity. The relationship between oxygen concentration and ischemic stroke has not been studied too much, but the effect of hyperbaric oxygenation on the prevention and treatment of stroke patients is remarkable [38, 39]. While there are fewer studies on the effect of wind speed on ischemic stroke, one study did find that the risk of AIS was significantly increased if the maximum wind speed was lower 3 days earlier [40]. In our study, although multivariate Poisson regression did not show a relationship between wind speed and stroke occurrence, in the univariate analysis, the increase of maximum wind speed can reduce the occurrence of stroke, which is consistent with the results of previous studies. However, among these typhoon-altered weather factors, some may be protective and others may be hazardous. Our study suggests that typhoon weather has a certain protective effect on ischemic stroke, but it is difficult to determine exactly which factors have a greater impact and further research is still needed.

This study also has some limitations. (1) It was a retrospective study, which may have resulted in recall bias and selection bias, loss of case data, incomplete records, recording errors, etc. The retrospective nature of the study inherently limits the ability to infer causality. Future prospective studies should be conducted to further verify the relationship between weather and AIS. (2) Since the COVID-19 outbreak began in China at the end of 2019, people were afraid to gather in crowded places, and generally did not go to hospitals if there were no special emergencies. Moreover, from January 17 to March 27, 2020, southern Zhejiang Province implemented a home quarantine policy due to severe epidemic conditions, which may lead to a lack of data on some patients. In addition, since people were almost at home during this time, the effect of outdoor weather on people was reduced, which may also affect the accuracy of our

results. (3) Meteorological parameters were measured fixed at the Wenzhou Meteorological Bureau and may not accurately reflect the patient's exposure at that time. (4) We designated the first day of the emergency room visit as the onset of the stroke, which may not be the actual time of the stroke. (5) The relative risks of temperature and water vapor pressure in our study were 1.021(95% CI 1.008–1.033) and 1.036(95% CI 1.006–1.067) respectively, which can only be described as weakly related to the occurrence of stroke, and the fit of the model may not be particularly excellent. These may be because the influence of non-meteorological factors on stroke is more important.

Conclusion

Stroke is an acute cerebrovascular disease with high mortality and disability. In southern Zhejiang Province of China, there is a correlation between the occurrence of acute ischemic stroke and weather change. Temperature and water vapor pressure may be risk factors, while typhoon occurrence may be a protective variable. The data from our study could be further utilized to develop preventive measures for acute ischemic stroke and coordinate hospital resources promptly and effectively.

Abbreviations

AIS	Acute ischemic stroke
CI	Confidence interval
GAM	Generalized additive model
Hmean	Mean humidity
ICD-10	International Classification of Diseases, Tenth Revision
RR	Relative risk
Tmax	Maximum air temperature
Tmean	Mean air temperature
WSmax	Maximum wind speed
WSmean	Mean wind speed
Pmean	Mean atmospheric pressure
Pvapor	Water vapor pressure

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12883-024-04012-4.

Supplementary Material 1

Acknowledgements

Not applicable.

Author contributions

Y.M. conceived the study. Y.Y., F.W., L.L., G.H., L.C. and X.Z. collected the data. Y.T., Y.C. and W.D. analyzed the data. Y.T. wrote the manuscript. Y.M. contributed to the manuscript revision. All authors reviewed the manuscript.

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The need for ethics approval and consent to participate were waived by the Ethics Committee in Clinical Research of the First Affiliated Hospital of Wenzhou Medical University due to the retrospective nature of this study. We only collected the number of cases with ischemic stroke. No other patient private information was collected and no follow-up of patients was required.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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References

1. Walter K. What is Acute ischemic stroke. JAMA. 2022;327(9):885.
2. Global regional, national burden of neurological disorders. 1990–2016: a systematic analysis for the global burden of Disease Study 2016. Lancet Neurol. 2019;18(5):459–80.
3. Wang YJ, Li ZX, Gu HQ, Zhai Y, Zhou Q, Jiang Y, Zhao XQ, Wang YL, Yang X, Wang CJ, et al. China Stroke statistics: an update on the 2019 report from the National Center for Healthcare Quality Management in Neurological diseases, China National Clinical Research Center for Neurological Diseases, the Chinese Stroke Association, National Center for Chronic and Non-communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention and Institute for Global Neuroscience and Stroke collaborations. Stroke Vasc Neurol. 2022;7(5):415–50.
4. O'Donnell MJ, Chin SL, Rangarajan S, Xavier D, Liu L, Zhang H, Rao-Melacini P, Zhang X, Pais P, Agapay S, et al. Global and regional effects of potentially modifiable risk factors associated with acute stroke in 32 countries (INTERSTROKE): a case-control study. Lancet. 2016;388(10046):761–75.
5. Guzik A, Bushnell C. Stroke epidemiology and risk factor management. Continuum (Minneap Minn). 2017;23(1):15–39.
6. Smith SC Jr. Reducing the global burden of ischemic heart disease and stroke: a challenge for the cardiovascular community and the United Nations. Circulation. 2011;124(3):278–9.
7. Louis S, Carlson AK, Suresh A, Rim J, Mays M, Ontaneda D, Dhawan A. Impacts of Climate Change and Air Pollution on neurologic health, Disease, and practice: a scoping review. Neurology. 2023;100(10):474–83.
8. Cao Y, Wang X, Zheng D, Robinson T, Hong D, Richtering S, Leong TH, Salam A, Anderson C, Hackett ML. Air pressure, humidity and stroke occurrence: a systematic review and meta-analysis. Int J Environ Res Public Health. 2016;13(7).
9. McArthur K, Dawson J, Walters M. What is it with the weather and stroke. Expert Rev Neurother. 2010;10(2):243–9.
10. Salam A, Kamran S, Bibi R, Korashy HM, Parray A, Mannai AA, Ansari AA, Kanikicharla KK, Gashi AZ, Shuaib A. Meteorological Factors and Seasonal Stroke Rates: a four-year Comprehensive Study. J Stroke Cerebrovasc Dis. 2019;28(8):2324–31.
11. Kuzmenko NV, Galagudza MM. Dependence of seasonal dynamics of hemorrhagic and ischemic strokes on the climate of a region: a meta-analysis. Int J Stroke. 2022;17(2):226–35.
12. Oberg AL, Ferguson JA, McIntyre LM, Horner RD. Incidence of stroke and season of the year: evidence of an association. Am J Epidemiol. 2000;152(6):558–64.
13. Jakovljević D, Salomaa V, Sivenius J, Tamminen M, Sarti C, Salmi K, Kaarsalo E, Narva V, Immonen-Räihä P, Torppa J, et al. Seasonal variation in the occurrence of stroke in a Finnish adult population. The FINMONICA Stroke Register. Finnish monitoring trends and determinants in Cardiovascular Disease. Stroke. 1996;27(10):1774–9.

14. Picón-Jaimes YA, Lozada-Martínez ID, Janjua T, Moscote-Salazar LR. Impact of time of day and season on Outcome in Acute ischemic stroke. Ann Neurol. 2021;90(3):518–9.
15. Swerdel JN, Janevic TM, Cosgrove NM, Kostis JB. The effect of Hurricane Sandy on cardiovascular events in New Jersey. J Am Heart Assoc. 2014;3(6):e001354.
16. Tarnoki AD, Turker A, Tarnoki DL, Iyisoy MS, Szilagyi BK, Duong H, Miskolczi L. Relationship between weather conditions and admissions for ischemic stroke and subarachnoid hemorrhage. Croat Med J. 2017;58(1):56–62.
17. Kokotailo RA, Hill MD. Coding of stroke and stroke risk factors using international classification of diseases, revisions 9 and 10. Stroke. 2005;36(8):1776–81.
18. Chan F, Francis O, Dodd L, Mahdi Z, Koblar SA. A hot topic–heat waves and stroke. Int J Stroke. 2014;9(7):858–9.
19. Zhou L, He C, Kim H, Honda Y, Lee W, Hashizume M, Chen R, Kan H. The burden of heat-related stroke mortality under climate change scenarios in 22 east Asian cities. Environ Int. 2022;170:107602.
20. Polcaro-Pichet S, Kosatsky T, Potter BJ, Bilodeau-Bertrand M, Auger N. Effects of cold temperature and snowfall on stroke mortality: a case-crossover analysis. Environ Int. 2019;126:89–95.
21. Lian H, Ruan Y, Liang R, Liu X, Fan Z. Short-term effect of ambient temperature and the risk of stroke: a systematic review and Meta-analysis. Int J Environ Res Public Health. 2015;12(8):9068–88.
22. Wang X, Cao Y, Hong D, Zheng D, Richtering S, Sandset EC, Leong TH, Arima H, Islam S, Salam A et al. Ambient temperature and stroke occurrence: a systematic review and meta-analysis. Int J Environ Res Public Health. 2016;13(7).
23. Chu SY, Cox M, Fonarow GC, Smith EE, Schwamm L, Bhatt DL, Matsouaka RA, Xian Y, Sheth KN. Temperature and precipitation associate with ischemic stroke outcomes in the United States. J Am Heart Assoc. 2018;7(22):e010020.
24. 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.
25. Dawson J, Weir C, Wright F, Bryden C, Aslanyan S, Lees K, Bird W, Walters M. Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland. Acta Neurol Scand. 2008;117(2):85–9.
26. Berginer VM, Goldsmith J, Batz U, Vardi H, Shapiro Y. Clustering of strokes in association with meteorologic factors in the Negev Desert of Israel: 1981–1983. Stroke. 1989;20(1):65–9.
27. Bullock B, Murray G, Meyer D. Highs and lows, ups and downs: Meteorology and mood in bipolar disorder. PLoS ONE. 2017;12(3):e0173431.
28. Li D, Zhang Y, Li X, Zhang K, Lu Y, Brown RD. Climatic and meteorological exposure and mental and behavioral health: a systematic review and meta-analysis. Sci Total Environ. 2023;892:164435.
29. Minor T, Sugg M, Runkle JD. Short-term exposure to temperature and mental health in North Carolina: a distributed lag nonlinear analysis. Int J Biometeorol. 2023;67(4):573–86.
30. Chen Z, Liu P, Xia X, Wang L, Li X. The underlying mechanisms of cold exposure-induced ischemic stroke. Sci Total Environ. 2022;834:155514.
31. Xie X, Atkins E, Lv J, Bennett A, Neal B, Ninomiya T, Woodward M, MacMahon S, Turnbull F, Hillis GS, et al. Effects of intensive blood pressure lowering on cardiovascular and renal outcomes: updated systematic review and meta-analysis. Lancet. 2016;387(10017):435–43.
32. Ernst E, Matrai A, Scherer A. Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling. Br Med J (Clin Res Ed). 1985;290(6461):74–5.
33. Chen X, Shang W, Huang X, Shu L, Xiao S, Jiang Q, Hong H. The Effect of Winter temperature on patients with ischemic stroke. Med Sci Monit. 2019;25:3839–45.
34. Neild PJ, Syndercombe-Court D, Keatinge WR, Donaldson GC, Mattock M, Caunce M. Cold-induced increases in erythrocyte count, plasma cholesterol and plasma fibrinogen of elderly people without a comparable rise in protein C or factor X. Clin Sci (Lond). 1994;86(1):43–8.
35. Hirel C, Berton L, Preda C, Richard O, Lambert Y, Pico F. Air pollution and humidity as triggering factors for stroke. Results of a 12-year analysis in the West Paris area. Rev Neurol (Paris). 2019;175(10):614–8.
36. Melnikov VN, Krivoschekov SG, Komlyagina TG, Rechkina SY, Consedine NS. Limb muscle hemodynamics and arterial distensibility depend on atmospheric pressure in hypertensive men. Biomed Environ Sci. 2013;26(4):284–94.
37. Hao GS, Fan QL, Hu QZ, Hou Q. Research progress on the mechanism of cerebral blood flow regulation in hypoxia environment at plateau. Bioengineered. 2022;13(3):6353–8.
38. Cozene B, Sadanandan N, Gonzales-Portillo B, Saft M, Cho J, Park YJ, Borlongan CV. An extra breath of fresh air: hyperbaric oxygenation as a stroke therapeutic. Biomolecules. 2020;10(9).
39. Schäbitz WR, Schade H, Heiland S, Kollmar R, Bardutzky J, Henninger N, Müller H, Carl U, Toyokuni S, Sommer C, et al. Neuroprotection by hyperbaric oxygenation after experimental focal cerebral ischemia monitored by MRI. Stroke. 2004;35(5):1175–9.
40. Gunes H, Kandis H, Saritas A, Dikici S, Buyukkaya R. The relationship between ischemic stroke and weather conditions in Duzce, Turkey. World J Emerg Med. 2015;6(3):207–11.

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