Meteorological Factors Related to Emergency Admission of Elderly Stroke Patients in Shanghai: Analysis with a Multilayer Perceptron Neural Network

Authors' Contribution:
Study Design **A**
Data Collection **B**
Statistical Analysis **C**
Data Interpretation **D**
Manuscript Preparation **E**
Literature Search **F**
Funds Collection **G**

ABCDE **Guilin Meng***
BCD **Yan Tan***
BCD **Min Fang**
BCD **Hongyan Yang**
AFG **Xueyuan Liu**
AFG **Yanxin Zhao**

Department of Neurology, Tenth People's Hospital, Tongji University, Shanghai, P.R. China

* Equal contributors

Corresponding Authors: Xueyuan Liu, e-mail: lxytj@163.com, Yanxin Zhao, e-mail: zhao_yanxin@126.com
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Background: The aim of this study was to predict the emergency admission of elderly stroke patients in Shanghai by using a multilayer perceptron (MLP) neural network.

Material/Methods: Patients (>60 years) with first-ever stroke registered in the Emergency Center of Neurology Department, Shanghai Tenth People's Hospital, from January 2012 to June 2014 were enrolled into the present study. Daily climate records were obtained from the National Meteorological Office. MLP was used to model the daily emergency admission into the neurology department with meteorological factors such as wind level, weather type, daily maximum temperature, lowest temperature, average temperature, and absolute temperature difference. The relationships of meteorological factors with the emergency admission due to stroke were analyzed in an MLP model.

Results: In 886 days, 2180 first-onset elderly stroke patients were enrolled, and the average number of stroke patients was 2.46 per day. MLP was used to establish a model for the prediction of dates with low stroke admission (≤4) and those with high stroke admission (≥5). For the days with low stroke admission, the absolute temperature difference accounted for 40.7% of admissions, while for the days with high stroke admission, the weather types accounted for 73.3%.

Conclusions: Outdoor temperature and related meteorological parameters are associated with stroke attack. The absolute temperature difference and the weather types have adverse effects on stroke. Further study is needed to determine if other meteorological factors such as pollutants also play important roles in stroke attack.

MeSH Keywords: Meteorological Concepts • Neural Networks (Computer) • Syncope

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Background

Stroke is one of the leading causes of death and disability in China and worldwide [1–4]. To investigate the factors related to stroke attack has been a global challenge. A variety of epidemiological studies have evaluated the relationship between stroke and meteorological variables. Most studies focused on the temperature related factors, such as heat wave, cold wave, and extreme temperature. Some studies suggested that cold temperature increased risks for stroke [5,6] while others indicated that high temperature was positively correlated with stroke attack [7–9]. Temperature fluctuation has a closer relationship with stroke attack than the absolute temperature value [10]. However, the impact of other meteorological factors on health has not been well described in available studies [11,12]. The weather situation is complicated because of numerous meteorological variables, including daily temperature, wind, and weather types. The effects of these factors on hospital admission vary among different regions or cities [13,14]. Previous findings on this issue were largely confusing and conflicting. Thus, it is necessary to clarify these relationships, which is helpful for the clinical management and prevention of stroke attack.

It is likely that the changes in weather conditions contribute to a higher stroke incidence. It has been reported that the elderly are more vulnerable to adverse weather conditions [15], which is related to the compromised capacity to detect outside weather conditions and the weakened ability to regulate body system in response to these changes [16,17]. In addition, the elderly usually have concomitant diseases such as hypertension, which are vulnerable to the influence of extreme weather stress. The assessment of vascular risk factors has demonstrated that high blood pressure remains the principal risk factor for both ischemic and hemorrhagic stroke [18,19]. Some elderly people live without air-conditioning, which may increase the risk for stroke secondary to the extreme temperature stress [20,21].

A model of meteorological factors to stroke is needed in predicting the admission to emergency department that may reflect the incidence of stroke. Artificial neural networks (ANNs) can be employed to describe the relationship and predict the trend [22,23]. The fact that ANNs do not rely on any assumption of relationship between input variables is an advantage over component analysis and multivariate analysis. The most commonly used ANN in clinical practice is the multilayer perceptron (MLP) [24,25]. In the past decades, MLP has been widely used in clinical practice. In the present study, the elderly patients were recruited, and MLP was employed to investigate effects of various meteorological factors on emergency admissions due to stroke. In this study, a model was established to predict the number of patients admitted to the Emergency Department due to stroke, aiming to find a reliable system for evaluating the emergency stroke admissions.

Material and Methods

Study design and subjects

The primary outcome of this study was the daily number of stroke patients admitted to the Emergency Department of Shanghai Tenth People's Hospital. Information on the emergency admission (such as the date of admission, diagnosis on admission, age, and sex) was collected. Patients admitted into the Emergency Department of Neurology between January 2012 and June 2014 were recruited into the present study. The types of stroke were determined according to the Trial of Org 10172 in Acute Stroke Treatment criteria. In the present study, stroke was classified as cerebral infarction, intracerebral hemorrhage (ICH), and subarachnoid hemorrhage (SAH). In our hospital, the Outpatient Department is open on weekends and holidays, and thus results were less affected by the calendar. Patients with any trauma caused by ICH and SAH and those younger than 60 years were excluded from this study. Cerebral infarction, SAH, and ICH were diagnosed by cranial computerized tomography (CT) or magnetic resonance imaging (MRI).

Meteorological measurements

Shanghai is a northern Chinese subtropical city with 4 distinct seasons [26]. Sunshine and rainfall are abundant, and 60% of the rainfall occurs between May and September. It has a mild and humid climate, a short spring and autumn, and long winter and summer [27]. In Shanghai, the average temperature throughout the year is about 16.6°C, the highest temperature from June to August is up to 40°C, and the lowest temperature from January to February is nearly –5°C.

Meteorological data in the same period were obtained from the National Meteorological Bureau, including the average temperature, highest temperature, lowest temperature, air pressure, vapor pressure, relative humidity, wind speed, precipitation, and sunshine. Single pressure, vapor pressure, relative humidity, precipitation, and sunshine are always noticed and are not convenient for clinical use. Thus, these factors (pressure, vapor pressure, relative humidity, precipitation, and sunshine) were classified as weather type groups, such as sunny, cloudy, rainy, thunderstorm, snow, and sleet. Absolute daily temperature variation before admission was calculated.

MLP

First, all the meteorological parameters and those related to admission were used to establish a database. Statistical analysis was performed using SPSS for Windows 19.0 package. The changes in meteorological parameters were plotted over time. Second, the MLP model was established.

Table 1. Number of patients admitted due to stroke from January 2012 to June 2014.

Diseases	Total (%)		Male (%)		Median age
CI	1659	(76.1%)	977	(58.9%)	66.1
ICH	351	(16.1%)	195	(55.7%)	61.7
SAH	170	(7.8%)	75	(44.1%)	61.1
Total	2180		1247	(57.2%)	65.0

IS – ischemic stroke, ICH – intracerebral hemorrhage, SAH – subarachnoid hemorrhage.

Table 2. Meteorological parameters from January 2012 to June 2014.

Meteorological parameters	Mean/median (lowest–highest)	
Maximum temperature	20.54	(2–38)°C
Lowest temperature	14.09	(–3–29)°C
Average temperature	17.32	(0–33)°C
Absolute temperature difference	2.01	(0–13)°C
Wind level	3.44	(0–9)
Weather type	1.00	(1-6)

Weather type: sunny=1, cloudy=2, rainy=3, thunderstorm=4, snow=5, sleet=6.

To determine the effectiveness of ANNs, a series of random numbers was used as control. The key of MLP was to form the training, testing, and prediction sets for the ANNs. The training set was used to optimize characteristics of the model, and the testing set to assess the generalization capabilities of a given network, while the validation set was used to assess the formed network.

It was difficult to establish a prediction model to accurately predict how many stroke patients would visit our Neurology Emergency Department. Based on our experience, if the number of stroke patients was more than 4, the daily work load would be heavy. Thus, from January 2012 to June 2014, these dates were divided into 2 groups according to the number of stroke patients admitted: low admission group (≤4; group 1) and high admission group (≥5; group 2).

Then, the dates in group 1 and group 2 were randomly divided into 10 equal groups independently, in which the training, testing, and prediction sets for the network were n: m: (10-n-m) (n, m, and 10-m-n were all integers).

Finally, meteorological factors, including weather type, wind speed, daily highest temperature, lowest temperature, average temperature, and absolute temperature difference, were all inputted into these 2 analysis sets. According to the validity of the prediction sets, poor validity data were used for re-modeling until the validity was ≥95%.

Results

Among 886 days, 2180 first-ever elderly stroke patients were enrolled; the average number of stroke patients was 2.46 per day. Of these patients, 76.1% had a primary IS, 16.1% had ICH, and 7.8% had SAH. There were no differences in the proportion of male patients and the median age between the CI group and ICH group. The highest temperature reached 38°C, the lowest temperature dropped to -3°C, and the maximum absolute temperature difference was 13°C. The wind level was 3-4 in a majority of dates (range: 0-9). On these dates, it presented characteristics of subtropical monsoon climate: fine, cold, and dry in winter, while low pressure, hot, and rainy in summer (Tables 1 and 2).

The proportions of patients with ICH and SAH were low, the early testing and modeling were not ideal; therefore IS together with ICH and SAH was employed for modeling.

The number of dates that 5 or more stroke patients were admitted was relatively small and discrete. In most of these dates, the number of patients admitted was 2–3 (58.2%). The number of stroke patients admitted was delineated with dates, and results showed various peaks in the number of stroke patients admitted throughout the year. Overall, the number of patients admitted between February and June was slightly higher than in other months. However, the number of patients admitted had no a linear relationship with meteorology factors. The number of patients admitted tended to increase when the temperature fluctuation was >5°C (Figure 1).

MLP was used to establish the prediction model of patients' number for 2 groups. Among 886 days from January 2012 to June 2014, 736 days were included in group 1 and 50 days in group 2. There was still no an ideal model for the 2 groups
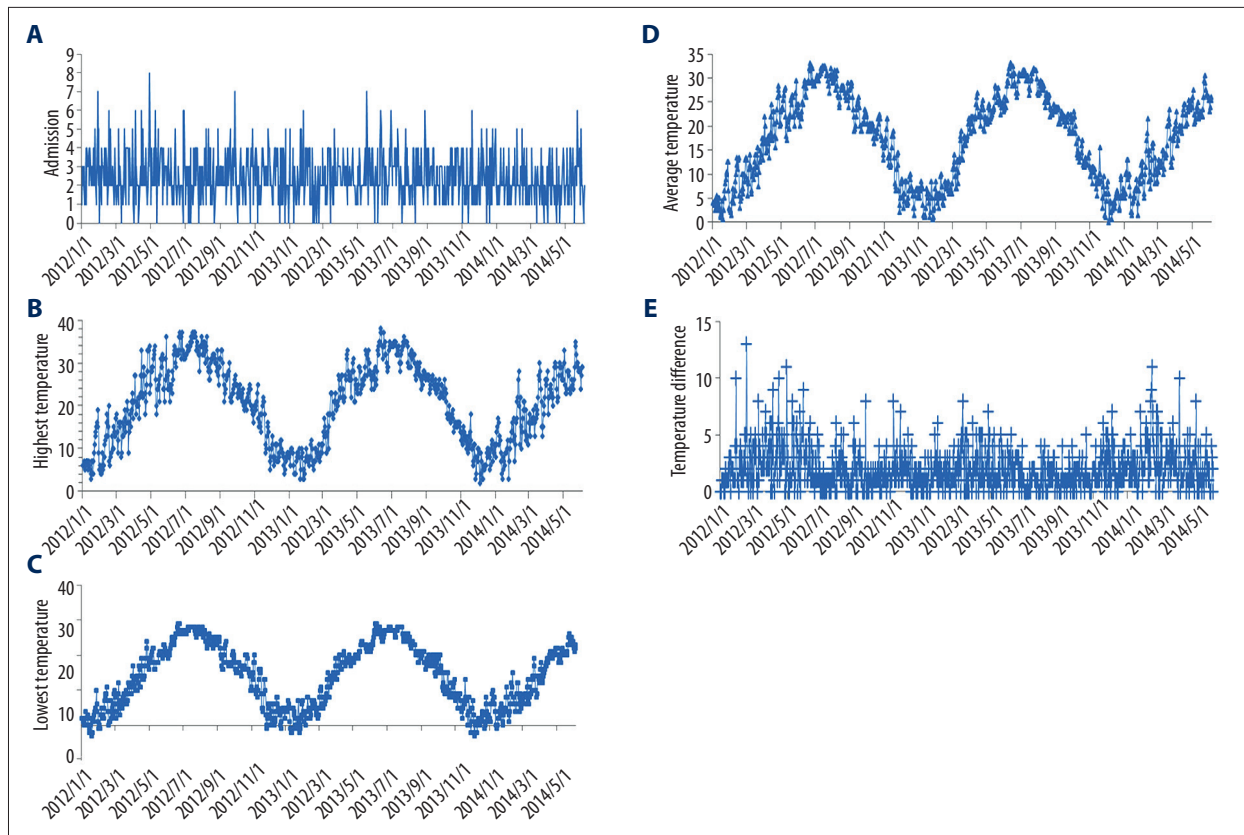
Figure 1. The daily number of stroke patients. The daily number of stroke patients admitted into the Emergency Department (**A**) and daily highest temperature (**B**), lowest temperature (**C**), average temperature (**D**), and absolute temperature difference (**E**) between January 2012 and June 2014.

Table 3. Model 1 and model 2 established with MLP.

Groups	Group 1#			Group 2		
MLP sets	Training	Testing	Prediction	Training	Testing	Prediction
	560	70	70	40	5	5
Models	Model 1			Model 2		
Validity*	97.2%			97.0%		

The dependent variable: number of patients admitted; # 6 days were randomly removed in order to modeling with MLP; * the validity of both models was >90%; MLP: multilayer perceptron neural network; Group 1, small number of stroke patients admitted (≤4); Group 2, large number of stroke patients admitted (≥5).

integrated; therefore, 2 models were established: model 1 for group 1, and model 2 for group 2. Since the dates in group 1 and group 2 were randomly divided into 10 equal subgroups, 6 days were removed in group 1. In 2 groups, the ratio of training, testing, and prediction sets for the ANNs were 8:1:1. Results showed that the validity of model 1 for group 1 was 97.2% and that of model 2 for group 2 was 97.0% (Table 3).

The intends probability and gain of group 1 (Figure 2) showed that model 1 was stable and reasonable to explain the influence

of weather factors on the small number of stroke patients admitted (>80%), while it was not applicable to group 2 (<20%).

Intends probability and gain of group 2 (Figure 3) showed the model 2 was stable and reasonable to explain the influence of weather factors on the large number of stroke patients admitted (nearly 90%), while it was not applicable to group 1 (<5%).

For dates on which few stroke patients were admitted, the absolute temperature difference accounted for 40.7% of
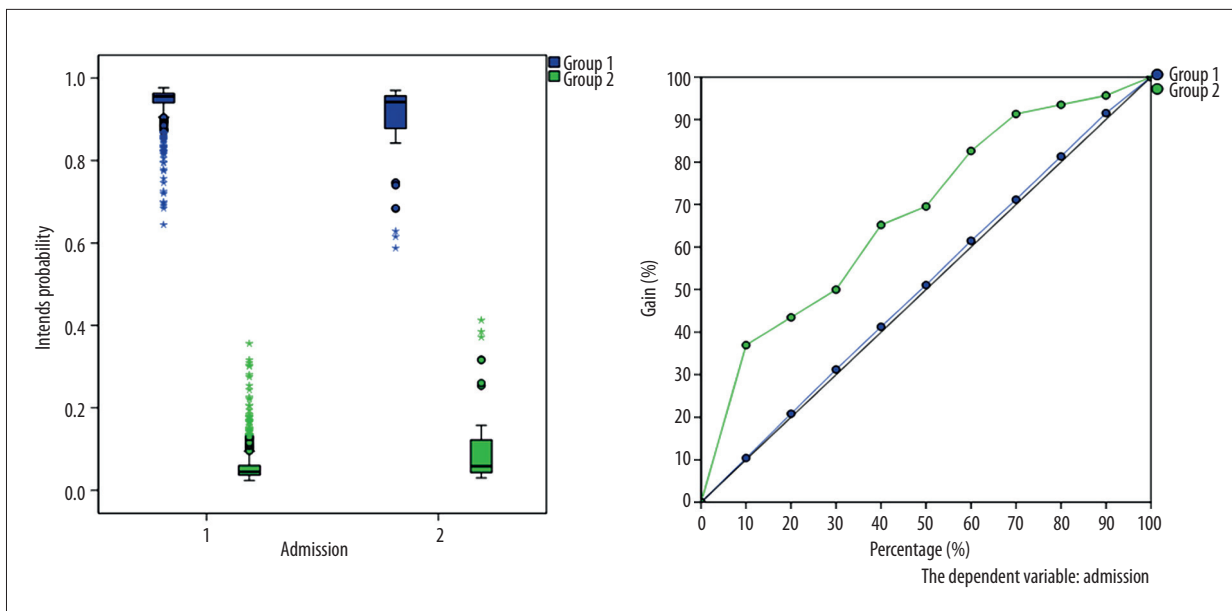
Figure 2. Intends probability and gain of model 1. For intend probability, the closer to 1.0, the more stable the model, and for gain, the closer to diagonal, the more reasonable the model.
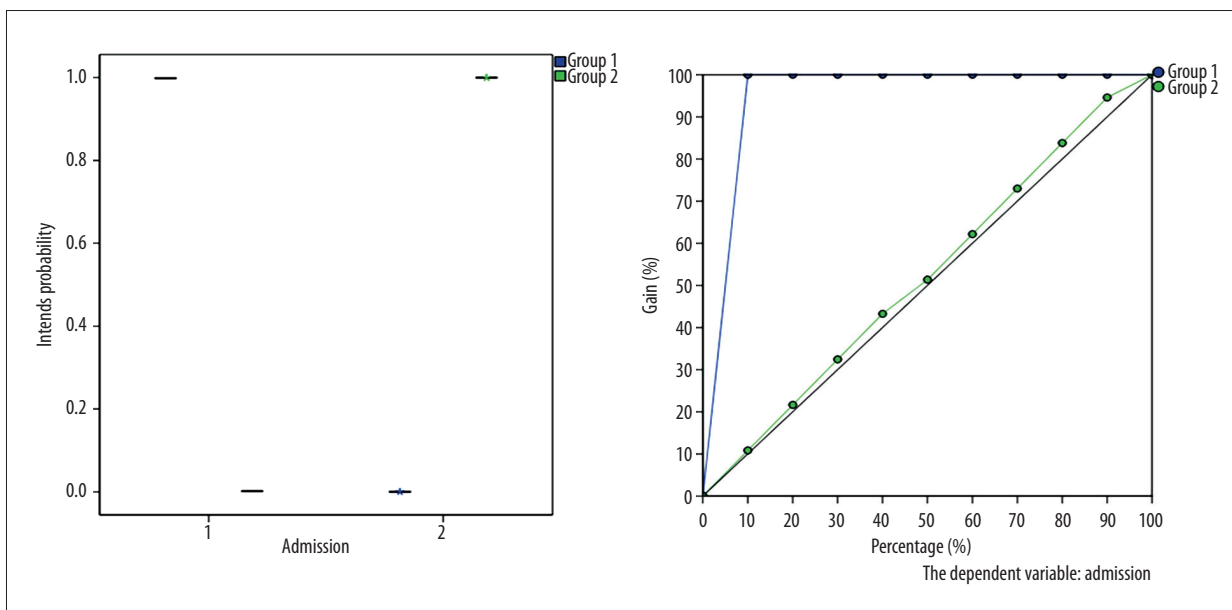
Figure 3. Intends probability and gain of model 2. For intend probability, the closer to 1.0, the more stable the model, and for gain, the closer to diagonal, the more reasonable the model.

admissions; while for dates on which more stroke patients were admitted, weather types accounted for 73.3% of admissions (Tables 4, 5 and Figure 4).

Within almost 2 months after June 2014, further analysis indicated that when the temperature changed (≥5°C) and the weather type remained stable, model 1 was appropriate to predict the number of stroke patients admitted; when the weather type changed while the temperature remained unchanged, model 2 was appropriate; and when the temperature and weather type changed simultaneously, both models were appropriate.

Because there was a clear relationship between weather conditions and stroke admission, incorporating meteorological forecasting into emergency medicine training may improve Emergency Department scheduling.

**Table 4.** Model 1: Importance of different meteorological parameters.

	Importance	Importance standardization
Wind level	0.221	54.4%
Weather	0.200	49.0%
Maximum temperature	0.036	8.9%
Lowest temperature	0.136	33.3%
Absolute temperature difference	0.407	100.0%

Model 1=0.407×absolute temperature difference + 0.221×wind level +0.200×weather type + 0.036×highest temperature + 0.136×lowest temperature.

Table 5. Model 2: The importance of the argument.

	Importance	Importance standardization
Wind level	0.074	10.1%
Weather	0.733	100.0%
Maximum temperature	0.030	4.1%
Lowest temperature	0.035	4.8%
Absolute temperature different	0.092	12.6%
Average temperature	0.036	4.9%

Model 2=0.733×weather type + 0.074×windlevel + 0.030×maximum temperature + 0.035×lowest temperature + 0.092×absolute temperature change + 0.036×average temperature.
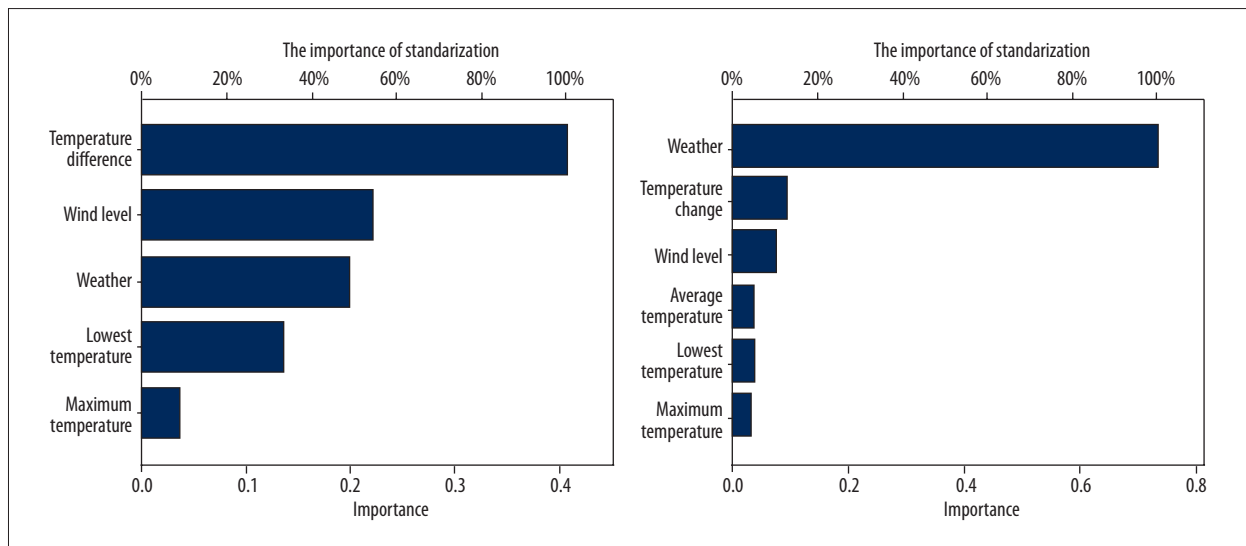
Figure 4. Importance of meteorological parameters in models 1 and 2.

Discussion

Outdoor temperature and related meteorological parameters are associated with stroke. Hospital admission reflects the incidence of stroke [26]. Findings on the influence of weather conditions on stroke are conflicting in available studies, which may be related to the different, but important, stresses due to excess heat/cold, weather type, and other factors. However, most studies have reported a seasonal peak in stroke morbidity and mortality in summer and/or winter [28–30].

The sun line and atmospheric pressure are related to weather type; therefore, the weather model was used to generalize the parameters above. These 2 models forecast future admissions to the Neurology Department under various weather conditions. The correlation coefficient between experimentally obtained activity concentration and predicted values was high (>0.95), indicating that this model can accurately forecast weather conditions. This high correlation coefficient indicates that correct meteorological parameters are valuable for clinical practice. A positive sign of the correlation coefficient between these parameters and activity concentration seems quite logical. The various weights for meteorological parameters and their association with stroke admission might explain the effects of weather conditions on stroke attack. These results showed that absolute temperature difference and weather types were negatively related to stroke attack. However, both models were only applicable in our hospital, and whether these data reflect the stroke morbidity in Shanghai is unclear. Multicenter studies are required to confirm these findings and determine if other meteorological factors, such as pollutants, also play important roles in stroke attack.

There are plausible physiological explanations for these associations. Vasoconstriction occurs as a response to ambient temperature drop, in an attempt to divert blood flow to important organs [29]. This increases the systemic vascular resistance and causes blood pressure to rise, which has been observed in real life. Cerebral blood flow has also been shown to reduce the following temperature drop, which then increases the risk for thrombotic complications. When the temperature increases dramatically, it may lead to increased blood flow into the vital vascular beds, such as the cerebral vasculature, which theoretically increases the risk for hemorrhage [31]. Impaired endothelial function (assessed by flow-mediated vasodilatation) has been observed following daily temperature increase [32,33]. These findings suggest that the reasons for the relationship between weather conditions and stroke attack are complex, and more supporting evidence is needed.

Conclusions

In the Emergency Department, clinicians should be aware that weather conditions are closely related to stroke attack. This study demonstrates that absolute temperature difference and weather types have adverse effects on occurrence of stroke. Further study is needed to determine if other meteorological factors such as pollutants also play crucial roles in stroke attack.

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