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# Ambient Temperature Change Increases in Stroke Onset: Analyses Based on the Japanese Regional Metrological Measurements

Ichiro Takumi[1,2], Masahiro Mishina[2,3], Shushi Kominami[2], Takayuki Mizunari[2], Shiro Kobayashi[2], Akira Teramoto[4,5] and Akio Morita[5]

[1]Department of Neurosurgery, Nippon Medical School Musashi Kosugi Hospital
[2]Neurological Institute, Nippon Medical School Chiba Hokusoh Hospital
[3]Department of Neuro-pathophysiological Imaging, Graduate School of Medicine, Nippon Medical School
[4]Tokyo Rosai Hospital
[5]Department of Neurosurgery, Graduate School of Medicine, Nippon Medical School

**Background:** Relationships between various climate factors and stroke have long been a subject of investigation. The present study investigated in a single medical center the effects of periodic temperature changes on the onset of intracerebral hemorrhage (ICH), subarachnoid hemorrhage (SAH), atherothrombotic infarction (AI), lacunar infarction (LI), cardiogenic embolism (CE), and transient ischemic attack (TIA).
**Methods:** The subjects were 4,310 patients who had been hospitalized because of hemorrhagic or ischemic stroke from January 2000 through December 2005. Ambient temperature data were collected from the Japan Meteorological Agency Database. The following factors were analyzed: number of stroke onsets per day; mean, maximum, and minimum ambient temperatures; and differences between the mean temperatures on the onset day and the previous week. Relationships between temperature factors and totals based on stroke subtypes were assessed by means of regression analyses with a standard least squares model controlling for specific covariates.
**Results:** The daily admissions for ICH, SAH, AI, LI, and CE increased when the mean temperature on the onset day was 1℃ lower than that of the previous week. Decreases in minimum ambient temperature predicted increased numbers of admissions for ICH and for SAH. Conversely, a 1℃ increase in maximum ambient temperature significantly affected ICH, AI, and CE admissions. There was no definitive relationship between temperature change and admissions for TIA.
**Conclusion:** Both absolute and comparative changes in ambient temperature are related to increased onsets of hemorrhagic and ischemic stroke in Japan. (J Nippon Med Sch 2015; 82: 281–286)

**Key words:** ambient temperature, weather, hemorrhagic stroke, ischemic stroke

## Introduction

Blood vessels in the human skin contract at low ambient temperatures and extend at high temperatures[1]. Blood pressure also increases at low ambient temperatures[2–8]. With these factors, the number of patients of hospitalized for strokes tends to increase during cold seasons[9–12]. Furthermore, the incidence of ischemic stroke tends to increase at high temperatures[13]. In addition to temperature extremes potentially influencing stroke onset, comparative temperature change also appears to be a factor. Although several studies have examined the effect of absolute ambient temperature on stroke onset, few studies have examined the role of relative temperature change[14]. Therefore, the present study investigated the effects of changes in both absolute and relative ambient temperatures on the number of patients admitted for stroke at our medical center. The present study also assessed how temperature factors influence different stroke subtypes

Correspondence to Ichiro Takumi, MD, PhD, Department of Neurological Surgery, Nippon Medical School Musashi Kosugi Hospital, 1–396 Kosugi-cho, Nakahara-ku, Kawasaki, Kanagawa 211–8533, Japan
E-mail: takumi@nms.ac.jp
Journal Website (http://www.nms.ac.jp/jnms/)

during the acute phase.

## Materials and Methods

### Subjects

The present study retrospectively evaluated data from 4,310 patients who had, for an acute stroke, been admitted to Nippon Medical School Chiba Hokusoh Hospital. This hospital is located in the northwest part of Chiba Prefecture, Japan, and is 46.7 km from the city of Tokyo and 16.1 km away from Tokyo Narita Airport[15]. The hospital is an active regional stroke center composed of modern stroke-care units equipped with stroke nurses, a "stroke hotline" telephone system enabling direct communication between local general practitioners and the stroke care unit, and a helicopter emergency medical service with qualified physicians on board. A unique feature of our center is that patients do not come from a broad range of areas, which is a feature of all other medical emergency services in Japan. The institution is the only comprehensive stroke-care unit in the region, which enables a regionally comprehensive study at a single stroke center.

The present study investigated the number of cases of stroke per day from January 2000 through December 2005 (2,192 days). Cases were excluded if the date of stroke onset was unknown. Patients who were selected had an intracerebral hemorrhage (ICH), a subarachnoid hemorrhage (SAH), an atherothrombotic infarction (AI), a lacunar infarction (LI), a cardiogenic embolism (CE), or a transient ischemic attack (TIA). Diagnoses of stroke subtype were defined according to criteria from the Trial of Org 10,172 in the Acute Stroke Treatment classification system[16]. Computed tomography of the brain was performed with a CT-W3000AD scanner (Hitachi Medical Co., Tokyo) upon admission for all patients. Within 2 days of admission, $T_2$-weighted and diffusion-weighted magnetic resonance images were obtained with a Signa Infinity 1.5-tesla machine (GE Healthcare, Milwaukee, WI, USA.) to identify recent ischemic strokes. Two physicians (I.T. and M.M.) reviewed neuroimaging data to determine the stroke subtypes through consensus. Informed consent was obtained from all patients or family members.

All patients brought to the hospital by ambulance from within Chiba Prefecture (5,156 km$^2$ in area) were included in this study. Patients brought from other prefectures were excluded, as different climate factors from different regional blocks could complicate our data analysis. Patients brought from Tokyo Narita Airport were included, but those believed to have initial symptoms before landing at the airport were excluded.

### Ambient Temperature

A database from the Japan Meteorological Agency was used for climate analysis. The following meteorological factors were acquired by an automated data acquisition system, which includes more than 1,300 locations in Japan, and every hour measured ambient temperature, precipitation (rainfall), hours of sunlight, and wind direction and speed. All data acquisitions were based on Japan Meteorological Agency policies. We used temperature data acquired from the closed system to our institution, 9.5 km apart, at latitude 35°43' N and longitude 140°12' E.

### Statistical Analyses

A relational database of patient information regarding admission and temperature data was created with the program FileMaker Pro version 12 (FileMaker Inc., Santa Clara, CA, USA). We imported the temperature data, such as mean, maximum, and minimum ambient temperatures of a particular day, into the database. By means of the database and calculations that we had developed we analyzed differences between the mean temperatures of a day and the previous week and the number of strokes, distinguished by subtype, to be onset among hospitalized patients. Relationships between temperature factors and the onset of stroke subtypes were assessed via regression analyses with a standard least-squares model controlling for potential covariates. Independent variables were the mean, maximum, and minimum ambient temperatures and the difference between the mean temperatures of a day and the previous week. Dependent variables included the numbers of patients admitted per day for ICH, SAH, AI, LI, CE, and TIA. Statistical significance was set at $p<0.05$. Computations were performed with the software program JMP version 11.2.1 (SAS Institute Inc., Cary, NC, USA) on a Macintosh computer (Apple Inc., Cupertino, CA, USA).

## Results

The observed temperature was 14.7℃ ± 8.3℃ (mean ± SD) for the entire study period and ranged from an absolute minimum of −7.1℃ on January 15 and 16, 2001, to an absolute maximum of 37.8℃ observed on July 20, 2004. Over the 6-year study period, the average temperature change within a season was consistent (**Fig. 1**). The number of strokes showing onset was greater in the winter (December to February) (**Fig. 1**). The number of AI and CE tended to increase during the summer. The number

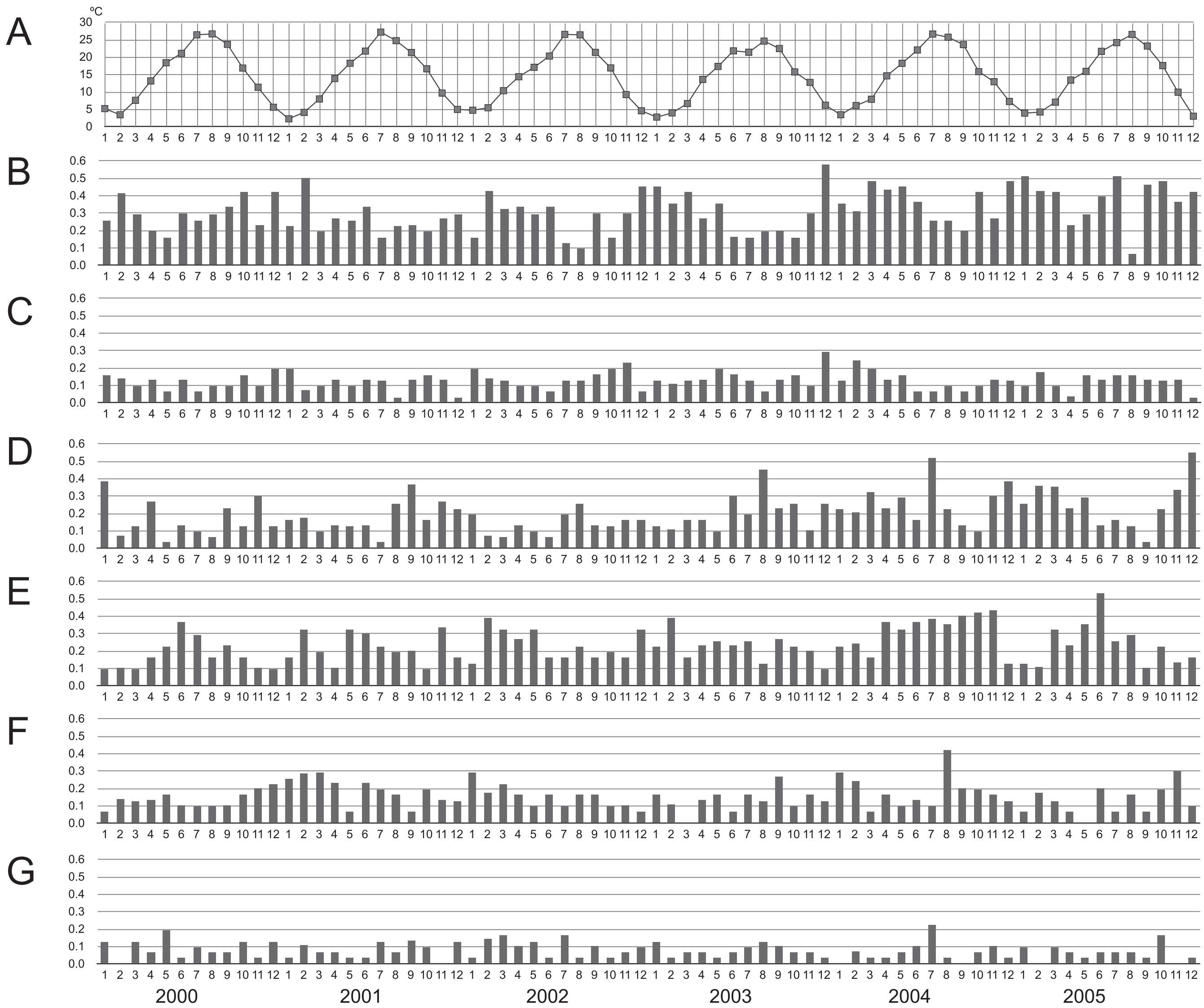


Fig. 1 Relationship between monthly mean ambient temperature and the daily number of stroke admissions based on subtype
**A**: monthly mean ambient temperature, **B**: monthly mean of admissions per day due to intracerebral hemorrhage, **C**: for subarachnoid hemorrhage, **D**: for atherothrombotic infarction, **E**: for lacunar infarction, **F**: for cardiogenic embolism, and **G**: for transient ischemic attack.

of TIAs was relatively small throughout the study period. The differences between the mean temperatures of a day and the previous week tended to be negative, indicating that the day was colder than the previous week, for all subtypes of stroke, except TIAs, on days when 2 or more patients with a stroke had been admitted (**Fig. 2**).

The characteristics of patients admitted to the hospital because of a stroke are shown in **Table 1**. Regression analysis with standard least-squares models showed that the number of patients admitted because of ICH, SAH, AI, LI, and CE increased when the difference between the mean temperatures of a day and of the previous week decreased by 1℃ (*p*=0.0180, 0.0146, 0.0121, 0.0151, and 0.0079, respectively) (**Table 2**). A decrease in minimum ambient temperature predicted an increase in the number of patients admitted because of ICH or SAH (0.0231 and 0.0193, respectively). Conversely, a 1℃ change in maximum ambient temperature significantly increased the number of admissions of patients with ICH, AI, and CE (*p*=0.0278, 0.0291, and 0.0130, respectively). There was no relationship between temperature change and the number of admissions for TIA or between the mean ambient temperature and stroke onset.

## Discussion

The present study indicates that the onset of both hemorrhagic and ischemic strokes increases on the basis of a

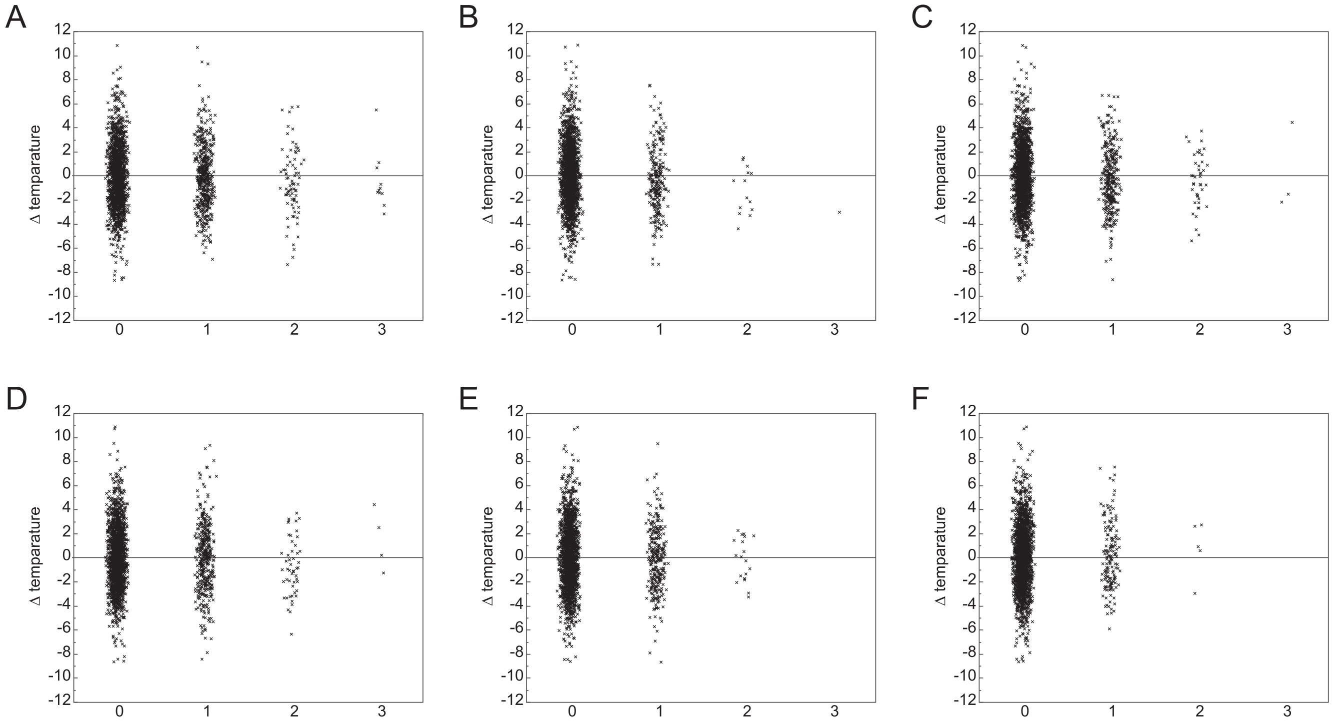


Fig. 2 Relationship between daily number of admissions and changes in ambient temperature
**A**: monthly mean of admissions per day for intracerebral hemorrhage, **B**: for subarachnoid hemorrhage, **C**: for atherothrombotic infarction, **D**: for lacunar infarction, **E**: for cardiogenic embolism, and **F**: for transient ischemic attack, Δ temperature: the difference between the mean daily temperature and mean temperature over the past 7 days.

Table 1 Characteristics of stroke patients

| Stroke subtype | Total (n) | Male (n) | Female (n) | Age, years (mean±SD) |
|---|---|---|---|---|
| ICH | 700 | 440 | 260 | 65.5±26.8 |
| SAH | 295 | 128 | 167 | 62.0±13.4 |
| AI | 443 | 268 | 175 | 68.9±10.9 |
| LI | 515 | 330 | 185 | 68.3±11.6 |
| CE | 332 | 197 | 135 | 71.7±11.1 |
| TIA | 201 | 127 | 74 | 62.1±15.0 |

ICH: intracerebral hemorrhage, SAH: subarachnoid hemorrhage, AI: atherothrombotic infarction, LI: lacunar infarction, CE: cardiogenic embolism, TIA: transient ischemic attack.

sudden decrease in ambient temperature. One previous study reported no significant relationship between temperature change and stroke onset; however, both relative increases and decreases in temperature have been found to be related to an increased risk for ischemic stroke[14]. Another study revealed a higher risk of acute ischemic stroke in the hours and days following colder temperatures, even after adjusting for air pollutant particles with a diameter of 2.5 μM or less, and regardless of season[17]. The present findings are consistent with those of other previous studies that found that either colder temperatures are associated with a higher risk for ischemic stroke[18–20] or that there is a null association[21]. The mechanisms underlying colder ambient temperature change and stroke occurrence have included blood pressure, platelet count or viscosity, cholesterol, heart rate, plasma fibrinogen, and peripheral vasoconstriction. Most hypotheses are based on an observed association between temperature and cardiac issues or markers or a systemic circulation analysis[17]. Reasons for null associations include different study samples, locations, and time periods[13,22].

Another finding of the present study is that absolute temperature is associated with stroke onset. Decreases in minimum temperature were a risk factor for hemorrhagic stroke, and increases in maximum temperature were a risk factor for ischemic stroke. However, a significant relationship was not found between a comparative increase in temperature and ischemic stroke but was found between a relative decrease in temperature and hemorrhagic stroke. Thus, a continuity of higher ambient temperature, not a relative change, might be a risk factor for ischemic stroke. Although not all studies support these relationships, a study in China has suggested that a

Table 2 Standard least-squares models regarding the relationship between changes in temperature and daily number of patients

| Variable | ICH | | SAH | | AI | | LI | | CE | | TIA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate | *p* value | Estimate | *p* value | Estimate | *p* value | Estimate | *p* value | Estimate | *p* value | Estimate | *p* value |
| MET | –0.0016 | 0.9334 | 0.0208 | 0.0838 | –0.0250 | 0.1058 | 0.0124 | 0.4526 | –0.0019 | 0.8812 | 0.0071 | 0.4379 |
| MAT | 0.0278* | 0.0044 | 0.0005 | 0.9285 | 0.0291* | 0.0002 | 0.0097 | 0.2408 | 0.0130* | 0.0473 | 0.0017 | 0.7110 |
| MIT | –0.0231† | 0.0166 | –0.0193† | 0.0013 | –0.0013 | 0.8660 | –0.0146 | 0.0760 | –0.0083 | 0.2011 | –0.0065 | 0.1547 |
| DMA | –0.0180† | 0.0002 | –0.0146† | <0.0001 | –0.0121† | 0.0015 | –0.0151† | 0.0002 | –0.0079† | 0.0142 | –0.0012 | 0.6003 |

*significant increase in the number of admissions coinciding with an increase in temperature and †coinciding with a decrease in temperature. Each whole model test was $p<0.0001$.

‡"Estimate" refers to the increase in the daily number of cases of stroke admitted when the temperature increased by 1°C.

Abbreviations: ICH: intracerebral hemorrhage, SAH: subarachnoid hemorrhage, AI: atherothrombotic infarction, LI: lacunar infarction, CE: cardiogenic embolism, TIA: transient ischemic attack, MET, mean ambient temperature for a particular day; MAT, maximum temperature for the day; MIT, minimum temperature for the day; DMA, differences between the mean temperatures of a day and the previous week.

higher temperature is a protective factor against ischemic strokes[11]. This discrepancy of relationships between temperature and incident rate of cerebral infarction differs from study to study might be due to a focus on weekly temperature changes in the present study. For example, a study in various Korean cities has found that higher temperatures increase ischemic stroke mortality (by 2.3% to 5.4%)[13]. Interestingly, the effect of higher temperatures on mortality has been observed only with ischemic strokes but not with hemorrhagic strokes[6,22,23]. A possible mechanism for the increased mortality rate of ischemic strokes is that heat induces patient dehydration, which increases blood viscosity.

The present study has also demonstrated that increases in maximum temperature are associated with the onset of ICH. Previous studies have found that hypertension is a major risk factor for ICH, even though several studies have found that blood pressure is lower in the summer than in the winter[1–3]. One study measuring ambulatory blood pressure has found that hot weather is associated with increases in systolic blood pressure during the night among elderly persons with hypertension[5]. Summer nights in Japan tend to have a higher temperature-humidity index (this means both the temperature and humidity are high); as a result, the entire day is uncomfortable. Thus, high temperatures at night might be related to the presence of insomnia, which might then encourage hypertension[24]. Because air conditioners are widely used in Japan, persons who have been exposed to a sudden decrease in temperature (resulting from being outside in the scorching heat and coming into a building with significantly cooler air) may experience a potentially detrimental change in high blood pressure.

A limitation of the present study was that it examined only ambient temperature rather than fluctuations in indoor temperature. Therefore, it was not possible to address the full variability in temperature exposure among individual conditions[10]. whether the subject was indoor or outdoor, at work or at rest. The relationship with other meteorological factors, such as humidity and atmospheric pressures, was not included in our results. This relationship should be examined in a future study.

Various meteorological factors have been investigated in terms of their relationships with the occurrence of strokes. These meteorological factors include hourly changes in ambient air temperature, atmospheric air pressure, and humidity. At times, these relationships are examined in terms of circadian rhythms (or more robust daily and monthly factors) to uncover seasonal relationships regarding stroke incidence. Data for the aforementioned hourly factors were automatically acquired from regional meteorological centers for a more precise analysis[25,26]. The present analysis was based on an automated data acquisition system in Japan as a way to compile a single medical institute case series for enhancing methodological precision.

On the basis of the present study, persons at high risk for stroke should be aware of various temperature fluctuations in their environment (particularly significant decreases in temperature). Although no one can completely avoid exposure to cold temperatures, one should reduce prolonged exposure to outdoor cold or ensure proper attire when exposed to those elements[1].

## Conclusion

Both absolute and relative decreases in ambient temperature appear to be related to the increased occurrence of hemorrhagic and ischemic strokes. Specifically, AI and CE occur more frequently with an increase in ambient temperature. Furthermore, exposure to a sudden decrease in temperature may increase the risk of stroke.

**Conflict of Interest:** None.

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