Original Contribution

Effect of Seasonal and Monthly Variation in Weather and Air Pollution Factors on Stroke Incidence in Seoul, Korea

Myung-Hoon Han, MD; Hyeong-Joong Yi, MD, PhD; Young-Soo Kim, MD, PhD; Young-Seo Kim, MD, PhD

Background and Purpose—The purpose of the present study was to determine whether seasonal and monthly variations in stroke incidence exist and whether they are related to meteorologic and air pollution parameters under similar weather and environmental conditions in selected areas of Seongdong district, Seoul, South Korea.

Methods—From January 1, 2004, to December 31, 2013, 3001 consecutive stroke events were registered in residents of selected areas of Seongdong district, Seoul, South Korea. The authors calculated the stroke attack rate per 100,000 people per month and the relative risk of stroke incidence associated with meteorologic and air pollution parameters. We also analyzed odds ratios with a 95% confidence interval for seasonal and monthly stroke incidence.

Results—The incidence of stroke in September was significantly higher (odds ratio, 1.233; 95% confidence interval, 1.042–1.468) compared with January. The seasonal ischemic stroke incidence in summer (odds ratio, 1.183; 95% confidence interval, 1.056–1.345) was significantly higher than in winter, whereas the seasonal incidence of intracerebral hemorrhage relative to winter was not significant. The mean temperature was positively correlated with ischemic stroke (relative risk, 1.006; P=0.003), and nitrogen dioxide (relative risk, 1.262; P=0.001) showed a strong positive correlation with intracerebral hemorrhage incidence among the older age group.

Conclusions—We demonstrated distinct patterns of seasonal and monthly variation in the incidence of stroke and its subtypes through consideration of the meteorologic and air pollution parameters. We therefore expect that these findings may enhance our understanding of the relationships between stroke and weather and pollutants. (Stroke. 2015;46:00-00. DOI: 10.1161/STROKEAHA.114.007950.)

Key Words: incidence ■ stroke ■ temperature

Stroke is the second most common cause of death and the leading cause of disability in South Korea. Each year, ≈105,000 Korean people experience a new or recurrent stroke. In spite of this high stroke incidence, to our knowledge, few published studies have been reported regarding seasonal and monthly variation in stroke incidence in South Korea. In contrast, there has been extensive research on seasonal variation in stroke from other parts of the world. Most studies have demonstrated that the incidence of stroke increases in the winter and spring and decreases in the summer and autumn. However, some studies have reported increases in the incidence of stroke in response to dramatic temperature changes in the spring and autumn, whereas in other studies, no seasonal variation has been demonstrated.

Because most previous studies have addressed large regions with varying climate, studies on smaller regions with similar weather and environments could provide important information on this topic.

Therefore, in the present study, we calculated the stroke attack rate to compare trends in ischemic and hemorrhagic stroke based on the season and month in selected areas of the Seongdong district of Seoul, Korea. We also estimated relative risk (RR) and odds ratio (OR) stratified by stroke subtype, sex, and age group based on monthly meteorologic and air pollution parameters. To minimize selection bias and weather and environmental heterogeneity, we selected regions relatively close to our hospital.

The purpose of the present study was to determine whether seasonal and monthly variation in stroke incidence exists and whether this variation is related to meteorologic and air pollution parameters under similar weather and environmental conditions in a relatively confined region.

Materials and Methods

Topography and Regional Climate

The Seongdong district (rectangular in shape; 6.55 mile²; population, 250,066) consists of 17 dongs and is located in an urban

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section of Seoul in northern South Korea. The population of Seoul is ≈10,000,000 individuals. The city is located at 37° north and 127° east and has a continental east coast climate. The weather in Seoul follows 4 distinct seasons, winter, spring, summer, and autumn. The average annual temperature is ≈12.2°C and ranges from −2.5°C in January to 27.9°C in August.

The population of the Seongdong district remained stable during the 10-year study period.

Area Selection

Hanyang University Medical Center is the sole regional tertiary hospital qualified to treat stroke in the Seongdong district, Seoul, South Korea. The Seongdong district is bounded by the Han River in the south and 2 branches of the Han River on the east. There are at most 2 nearby tertiary hospitals (1.94 and 2.33 miles from the border of the Seongdong district) located to the east and north in other districts. To minimize selection bias, we excluded 3 of 17 dongs located on the eastern and northern borders of the Seongdong district. The population included 164,329 adult inhabitants (>19 years) in 2013 based on the Korean population census. Patients within the selected areas can reach the Hanyang University Medical Center emergency unit within 12 minutes by car, and almost all emergent patients within the Seongdong district are obligated to be transferred to our hospital according to the guidelines of the Emergency Medical Services system.

Meteorologic and Air Pollution Data

The meteorologic variables studied included monthly measures of mean temperature, diurnal temperature range (the difference between the monthly average maximum and minimum temperatures), and average humidity for the 10-year study period. These data were obtained from the Meteorologic Administration of South Korea. Data on pollutants included monthly measures of average levels of particulate matter with an aerodynamic diameter <10 μm (PM<sub>10</sub>) and nitrogen dioxide (NO<sub>2</sub>) of the Seongdong district for the 10-year study period, which were obtained from the Climate and Air Quality Management Division of South Korea (please see Tables I–III in the online-only Data Supplement).

Patients

A total of 4,523 patients (>19 years of age, first-ever stroke; recurrent stroke counted as one, no evidence of trauma or brain tumor) were initially enrolled in this study. We then excluded 1,180 patients who were not eligible for this study for the following reasons: outside of the study area, 917; referred from another region, 161; discharge diagnosis coding error, 71; or missing address information, 31. In addition, we also excluded 342 patients diagnosed with subarachnoid hemorrhage because a recent study from the United States reported that seasonal trends in subarachnoid hemorrhage incidence mainly originated from cerebral aneurysm. If intracerebral hemorrhage (ICH) and subarachnoid hemorrhage presented together, we classified the hemorrhage according to the major site, then excluded cases of subarachnoid hemorrhage. We finally included 3,001 consecutive cases diagnosed as stroke in our hospital from January 1, 2004, to December 31, 2013.

All stroke patients were included in the stroke registry if their discharge diagnoses were coded as I61 or I63 according to the International Classification of Diseases, 10th Revision (ICD-10). Stroke subtypes were defined according to published criteria and ICD-10. The Clinical Research Center for Stroke registry (http://stroke-crc.or.kr/core/index.asp) was established in 2006 in South Korea and is supported by the Ministry of Health and Welfare to develop and supply critical pathway of stroke to meet Korean characteristics. To gather information in the period preceding the establishment of the Clinical Research Center for Stroke (2004–2007), all medical records were reviewed by 3 specialized research staff using an electronic medical record system database. Diagnosis was confirmed by CT or MRI in all cases.

A history of hypertension was defined as previous use of antihypertensive medication or through review of medical charts or a patient/guardian self reporting instead of through actual blood pressure readings because stroke is likely to elevate blood pressure. Diabetes mellitus was defined as random blood glucose ≥200 mg/dL on admission. History of smoking was defined as including former and current smokers (≥1 cigarette per day) and drinking history as former and current drinkers (at least once per month).

Besides patients within the Departments of Emergency Medicine, Neurology, and Neurosurgery, we performed a broad search of ICD codes of interest in all relevant departments to include patients diagnosed or treated for stroke outside and inside our hospital. Patients who died outside the hospital with a death certificate diagnosis of stroke were also included in the study.

This study was approved by the institutional review board of Hanyang University Medical Center.

Statistical Methods

Seasons were divided into winter (December through February), spring (March through May), summer (June through August), and autumn (September through November) on the basis of meteorologic reports. The χ<sup>2</sup> test was used to analyze seasonal differences in risk factors. The stroke attack rate was defined as the average number of strokes occurring in the study period per 100,000 people per month.

Poisson generalized linear regression models were used to model the risk of a patient presenting with stroke using a log-linkage function offset by the log of the population in each month from 2004 to 2013. Predictor variables included in these models were mean temperature, diurnal temperature range, humidity, PM<sub>10</sub>, and NO<sub>2</sub>. We scaled RR for temperature at increments of 1°C, for humidity at increments of 5%, and for pollutants at increments of 10 mg/m<sup>3</sup>. Poisson regression models were run for the group as a whole and then separately for stroke subtype, sex, and age group. Regression coefficients were transformed to reflect the RR difference in the response between tested and fixed variables using the exponential transformation, e<sup>β</sup>.

We described the OR with 95% confidence intervals (CIs) using uni- and multivariable logistic regression model for stroke subtypes, stratified by sex and age group based on meteorologic and air pollution factors. Multivariable logistic regression was performed to adjust for confounding meteorologic and air pollution parameters, including past medical history, age, and sex. In these analyses, we ran 2 separate logistic regression models depending on the independent variables as IS (coding 1) versus ICH (coding 0) and ICH (coding 1) versus IS (coding 0). To reduce confusion, we estimated ORs by switching between the 2 models based on the RR of the Poisson regression model (Tables IV–VIII in the online-only Data Supplement).

We calculated the ORs of seasonal and monthly stroke incidence with 95% CIs, using multinomial logistic regression. We drew β in the seasonal model relative to winter and 11β in the monthly model compared with January. The OR was calculated as e<sup>β</sup>, with a 95% CI using the exponential transformation, e<sup>β</sup>.

Results

Among all stroke (AS) patients, the mean age of stroke onset was 64.8 years (men, 62.0; women, 68.2). Of a total of 3,001 strokes, 2,202 were IS and 799 were ICH. Further, descriptive data and history of risk factors are shown in Table 1. Using a χ<sup>2</sup> model, there was no seasonal difference regarding the prevalence of stroke risk factors (Table 2).

Table 3 shows the crude monthly attack rates for total stroke and stroke subtypes with mean meteorologic and air pollution characteristic data. The monthly attack rate of AS was highest in September (17.7 per 100,000; 95% CI, 14.5–21.5) and was lowest in October (14.0; 95% CI, 11.7–16.0). A high...
Table 1. Characteristics of Patients With First-Ever Stroke in Selected Areas of the Seongdong District, Seoul, Korea, 2004 to 2013

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Selected Areas of the Seongdong District</th>
<th>AS, n=3001</th>
<th>IS, n=2202</th>
<th>ICH, n=799</th>
</tr>
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<tbody>
<tr>
<td>Overall</td>
<td>164,329</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>83,932 (51.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>80,397 (48.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 y</td>
<td>130,233 (79.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥60 y</td>
<td>34,966 (20.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1,665</td>
<td>1,170</td>
<td>495</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>1,336</td>
<td>1,032</td>
<td>304</td>
<td></td>
</tr>
<tr>
<td>Mean age (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>62.0</td>
<td>64.9</td>
<td>55.3</td>
<td></td>
</tr>
<tr>
<td>(13.4)</td>
<td>(12.3)</td>
<td>(13.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>68.2</td>
<td>70.2</td>
<td>61.4</td>
<td></td>
</tr>
<tr>
<td>(13.4)</td>
<td>(12.3)</td>
<td>(14.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>64.8</td>
<td>67.4</td>
<td>57.6</td>
<td></td>
</tr>
<tr>
<td>(13.8)</td>
<td>(12.6)</td>
<td>(14.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age distribution, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 y</td>
<td>1,010</td>
<td>564</td>
<td>446</td>
<td></td>
</tr>
<tr>
<td>≥60 y</td>
<td>1,991</td>
<td>1,638</td>
<td>353</td>
<td></td>
</tr>
<tr>
<td>Presence of risk factor history, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>1,689</td>
<td>1,271</td>
<td>418</td>
<td></td>
</tr>
<tr>
<td>(56.3)</td>
<td>(57.7)</td>
<td>(52.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>826</td>
<td>703</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>(27.5)</td>
<td>(31.9)</td>
<td>(15.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drinking alcohol</td>
<td>1,121</td>
<td>786</td>
<td>335</td>
<td></td>
</tr>
<tr>
<td>(37.4)</td>
<td>(35.7)</td>
<td>(41.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td>692</td>
<td>460</td>
<td>232</td>
<td></td>
</tr>
<tr>
<td>(23.1)</td>
<td>(20.9)</td>
<td>(29.0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data from a population census of the Seongdong district, Seoul, Korea, in 2013.

Table 2. Distribution of Risk Factors According to Season and Stroke Subtype

<table>
<thead>
<tr>
<th></th>
<th>Winter, %</th>
<th>Spring, %</th>
<th>Summer, %</th>
<th>Autumn, %</th>
<th>PValue*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>54.8</td>
<td>58.5</td>
<td>58.7</td>
<td>56.9</td>
<td>0.41</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>29.8</td>
<td>28.6</td>
<td>27.9</td>
<td>26.9</td>
<td>0.67</td>
</tr>
<tr>
<td>Alcohol use</td>
<td>38.2</td>
<td>39.7</td>
<td>36.7</td>
<td>39.7</td>
<td>0.60</td>
</tr>
<tr>
<td>Smoking</td>
<td>22.5</td>
<td>23.6</td>
<td>25.8</td>
<td>23.0</td>
<td>0.45</td>
</tr>
<tr>
<td>IS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>56.5</td>
<td>59.5</td>
<td>60.3</td>
<td>58.0</td>
<td>0.59</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>34.8</td>
<td>33.0</td>
<td>31.9</td>
<td>31.1</td>
<td>0.61</td>
</tr>
<tr>
<td>Alcohol use</td>
<td>36.3</td>
<td>38.8</td>
<td>34.5</td>
<td>36.8</td>
<td>0.52</td>
</tr>
<tr>
<td>Smoking</td>
<td>20.4</td>
<td>21.7</td>
<td>23.8</td>
<td>19.8</td>
<td>0.36</td>
</tr>
<tr>
<td>ICH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>50.9</td>
<td>56.1</td>
<td>53.1</td>
<td>53.5</td>
<td>0.76</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>18.3</td>
<td>16.7</td>
<td>14.7</td>
<td>13.9</td>
<td>0.62</td>
</tr>
<tr>
<td>Alcohol use</td>
<td>42.6</td>
<td>41.9</td>
<td>44.1</td>
<td>48.9</td>
<td>0.54</td>
</tr>
<tr>
<td>Smoking</td>
<td>27.2</td>
<td>28.6</td>
<td>32.4</td>
<td>33.0</td>
<td>0.54</td>
</tr>
</tbody>
</table>

AS indicates all stroke; ICH, intracerebral hemorrhage; and IS, ischemic stroke.

*Seasonal comparison, Chi square test.

incidence rate in September was also found for IS (13.3; 95% CI, 9.8–16.9), whereas in the ICH group, the incidence rate was highest in January (4.9; 95% CI, 3.3–6.3).

Table 4 summarizes the Poisson regression models run to assess the relationship between meteorologic and air pollution variables and risk of stroke presentation. The mean temperature was positively correlated with IS (RR, 1.006; 95% CI, 1.002–1.011; P=0.003 per 1°C increment). These data suggest that a 1°C increase in monthly mean temperature is associated with a 0.6% higher risk of IS. Similar patterns were also observed in men within AS (RR, 1.007; 95% CI, 1.000–1.013; P=0.044) and IS (RR, 1.012; 95% CI, 1.006–1.017; P<0.001). In the older age group, mean temperature was positively related to IS incidence (RR, 1.007; 95% CI, 1.002–1.012; P=0.007), whereas mean temperature was observed to have a negative correlation with ICH (RR, 0.985; 95% CI, 0.975–0.995; P=0.004). Only the older age group showed a positive correlation between ICH and diurnal temperature range (RR, 1.030; 95% CI, 1.005–1.055; P=0.020). No significant association was observed with humidity. Among air pollution variables, PM10 was negatively correlated with IS (RR, 0.970; 95% CI, 0.945–0.995; P=0.009, per 10 mg/m3 increment) and a significant negative correlation was observed in men (RR, 0.943; 95% CI, 0.911–0.977; P=0.002). Both PM10 (RR, 1.106; 95% CI, 1.039–1.178; P=0.002) and NO2 (RR, 1.262; 95% CI, 1.100–1.448; P=0.001, per 10 mg/m3 increment) showed a strong positive correlation with ICH incidence among the older age group.

We also observed a tendency toward positive correlation between IS and the mean temperature for an increase of 1°C and between ICH and pollutants for an increase of 10 μg/m3 on logistic regression. In addition, a negative correlation was observed between ICH and mean temperature for an increase of 1°C. Only the mean temperature was significant in the fully adjusted model (OR of IS over ICH, 1.015; 95% CI, 1.006–1.023; P=0.001). A positive association was observed with humidity. Among air pollution factors, PM10 was negatively correlated with IS (RR, 1.030; 95% CI, 1.005–1.055; P=0.020). No significant association was observed with PM10 and between ICH and pollutants for an increase of 10 μg/m3 on logistic regression. In addition, a negative correlation was observed between ICH and mean temperature for an increase of 1°C. Only the mean temperature was significant in the fully adjusted model (OR of IS over ICH, 1.015; 95% CI, 1.006–1.023; P=0.001). These data suggest that a 1°C increase in monthly mean temperature correlates with a 1.5% higher risk of IS incidence relative to ICH and vice versa.

We estimated stroke incidence using box-plot diagrams with descriptive statistics classified by the quartile groups of meteorologic and air pollution factors (Figures I and II in the online-only Data Supplement). This result suggests that a 1°C increase in monthly mean temperature correlates with a 1.5% higher risk of IS incidence relative to ICH and vice versa.

Figure 1 presents odds ratios with 95% CIs for seasonal incidence of stroke in spring, summer, and autumn with winter as the reference, as well as monthly incidence of stroke stratified by sex and age group with January as a reference using multinomial logistic regression. The September incidence was significantly higher (OR, 1.233; 95% CI, 1.042–1.468) compared with January, whereas there was no seasonal variation in stroke relative to winter. An elevated September stroke incidence was also observed for men (OR, 1.391; 95%
Table 3. Monthly Stroke Attack Rate and Average Monthly Temperature, Diurnal Temperature Range, Humidity and Air Pollution Characteristics of Seoul, South Korea, From January 1, 2004, to December 31, 2013

<table>
<thead>
<tr>
<th>Month</th>
<th>Stroke Attack Rate per 100 000 People per Month</th>
<th>Mean Temperature, °C</th>
<th>Diurnal Temperature, °C range</th>
<th>Humidity, %</th>
<th>PM&lt;sub&gt;2.5&lt;/sub&gt; μg/m&lt;sup&gt;3&lt;/sup&gt;</th>
<th>NO&lt;sub&gt;2&lt;/sub&gt; μg/m&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>14.4</td>
<td>9.5</td>
<td>4.9</td>
<td>2.5</td>
<td>21.4</td>
<td>54.9</td>
</tr>
<tr>
<td>February</td>
<td>14.5</td>
<td>10.0</td>
<td>4.5</td>
<td>0.6</td>
<td>25.4</td>
<td>52.5</td>
</tr>
<tr>
<td>March</td>
<td>14.4</td>
<td>10.5</td>
<td>3.9</td>
<td>5.3</td>
<td>23.4</td>
<td>53.3</td>
</tr>
<tr>
<td>April</td>
<td>15.9</td>
<td>11.6</td>
<td>4.3</td>
<td>11.9</td>
<td>22.2</td>
<td>53.2</td>
</tr>
<tr>
<td>May</td>
<td>14.6</td>
<td>10.2</td>
<td>4.4</td>
<td>18.2</td>
<td>21.0</td>
<td>58.4</td>
</tr>
<tr>
<td>June</td>
<td>15.0</td>
<td>11.5</td>
<td>3.5</td>
<td>22.9</td>
<td>17.8</td>
<td>63.6</td>
</tr>
<tr>
<td>July</td>
<td>16.2</td>
<td>12.5</td>
<td>3.7</td>
<td>24.8</td>
<td>13.5</td>
<td>77.5</td>
</tr>
<tr>
<td>August</td>
<td>16.1</td>
<td>12.0</td>
<td>4.1</td>
<td>26.3</td>
<td>16.1</td>
<td>71.8</td>
</tr>
<tr>
<td>September</td>
<td>17.7</td>
<td>13.3</td>
<td>4.4</td>
<td>21.6</td>
<td>19.2</td>
<td>65.8</td>
</tr>
<tr>
<td>October</td>
<td>14.0</td>
<td>11.1</td>
<td>2.9</td>
<td>15.5</td>
<td>21.9</td>
<td>60.1</td>
</tr>
<tr>
<td>November</td>
<td>14.1</td>
<td>10.0</td>
<td>4.1</td>
<td>7.6</td>
<td>24.2</td>
<td>58.7</td>
</tr>
<tr>
<td>December</td>
<td>15.9</td>
<td>11.8</td>
<td>4.1</td>
<td>−0.5</td>
<td>23.7</td>
<td>56.6</td>
</tr>
</tbody>
</table>

Data from the Meteorologic Administration and Climate and Air Quality Management Division of South Korea. AS indicates all stroke; ICH, intracerebral hemorrhage; IS, ischemic stroke; NO<sub>2</sub>, nitrogen dioxide; and PM<sub>2.5</sub>, particulate matter <10 mm in aerodynamic diameter.

Discussion

The present study demonstrates clear seasonal and monthly variation in the occurrence of stroke events in both men and women and across age groups. Monthly variation in IS and ICH stroke subtypes showed a nearly symmetrical shape relative to January in men and the older age group. In the seasonal data, mean temperature was higher in summer compared with winter. The months of September (OR, 1.404; 95% CI, 1.053–1.723) and July (OR, 1.314; 95% CI, 1.084–1.607) have high positive correlation with IS incidence. There was no significant relationship between ICH incidence and winter, and ICH incidence was lowest in October (OR, 0.587; 95% CI, 0.404–0.857). Similar patterns of monthly IS and ICH incidence were observed in men and the older age group.

We found no seasonal variation in history of conventional risk factors, which is in line with a recent study indicating that seasonal differences in stroke incidence are independent of other risk factors. Our findings are in line with a study by Berginer et al., in which the authors suggested that exposure to heat is likely to cause dehydration, increasing blood clotting factors. These effects in persons without vascular disease might cause no harm, but they could predispose older patients with vascular disease to thromboembolic episodes. In contrast, during cold conditions, when the blood is somewhat less viscous, blood volume and blood pressure is likely to decrease, and perfusion of the brain is favored because of peripheral vasoconstriction. This could increase the incidence of brain hemorrhage. The monthly mean maximum temperature, where this study was conducted is similar to that of Seoul. In our study, a positive correlation between mean temperature and IS incidence was observed in men. This might be explained by the fact that men are far more likely to engage in strenuous outdoor activity or work than women during heat waves. Korean women also culturally tend to avoid the sun, and the study area is urban where women are less likely to work outside compared with rural areas. In addition, there was a negative association between mean temperature and ICH incidence in the older age group. Similar findings were reported by a study in Italy. The authors described significant negative associations between mean temperature and all stroke hospitalizations, particularly ICH, with the greatest effect in people ≥65 years of age. Furthermore, highly significant positive relationships were observed between IS and average temperature for an increment of 5°C (day to day), especially when people ≥65 years of age were considered. Our findings are also similar to other studies, including those from South Korea.

A recent study reported a correlation between sunlight exposure and cerebral infarction. However, it was unclear whether the high incidence of cerebral infarction was caused by high insolation or high temperature. In addition, some studies have indicated that vitamin D insufficiency is associated with high blood pressure, which may increase hemorrhagic stroke. Snijder et al indicated that an association between poor vitamin D status and hypertension could potentially be mediated by elevated parathyroid hormone levels. Parathyroid hormone has a prosclerotic effect on vascular smooth muscle cells, which may contribute to vessel wall thickening and, consequently, to higher blood pressure, especially in older...
persons. In addition, vitamin D is provided by UVB-induced skin synthesis and, to a smaller extent, by absorption from food. However, these processes become less efficient with age. These hypotheses seem to fit well with our findings of the high ICH incidence among older patients in winter (when sun exposure is lowest).

Higher diurnal temperature changes are related to significantly higher hemorrhagic stroke incidence in the older age group; however, there was no significant association after adjusting the variables (see the online-only Data Supplement). An earlier study from Japan reported that diurnal temperature change may affect daily blood pressure or autonomic nervous system balance, and, if a considerable diurnal temperature change induces considerable hemodynamic change, it may trigger cerebral stroke. In addition, some studies reported stronger seasonality in stroke in older age groups than in younger ones, as seen in our study.

We found a September preponderance in the monthly incidence of AS and IS. Although this finding might be a consequence of insufficient data, Jimenez-Conde also describes greater daily variation in atmospheric pressure in autumn and winter as being highly relevant in seasonal peak IS incidence. Variation in atmospheric pressure may influence vessel walls and their endothelial function through endogenous inflammatory mechanisms. Psychological stress is reported to be a significant risk factor for stroke and coronary artery disease, even after adjustment for other conventional risk factors in middle-aged men. Readjusting to work after a short vacation in July/August could act as an additional stressor. However, the reason for the high incidence of AS and IS in September is not immediately apparent, and this observation needs further confirmation.

PM$_{10}$ per 10 mg/m$^3$ increment was associated with lower IS incidence and higher ICH incidence in our study; however, these relationships were not significant after adjusting for other variables. However, NO$_2$ was positively correlated with ICH incidence in the older age group even after adjustment (see the online-only Data Supplement). There have been prior studies that reported similar findings; however, to the best of our knowledge, there have been few studies considering the association between ICH and NO$_2$ in older persons. Some studies have reported an association between plasma fibrinogen and NO$_2$ and between elevated levels of particulates and increased plasma viscosity. However, further evaluation

| Table 4. Relative Risk and 95% Confidence Interval for All Stroke and Stroke Subtypes Stratified by Sex and Age Group, Based on 1°C Increments in Mean Temperature and Diurnal Temperature Range, 5% Increments in Humidity, and 10 μg/m$^3$ Increases in Air Pollutants |
|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
|                                  | Meteorologic Variables           |                                  | Air Pollution Variables           |
|                                  | Mean Temperature, °C             | Diurnal Temperature Range, °C    | Humidity, %                       | PM$_{10}$, μg/m$^3$               | NO$_2$, μg/m$^3$                  |
|                                  | RR (95% CI)                      | RR (95% CI)                      | RR (95% CI)                       | RR (95% CI)                       | RR (95% CI)                       |
| AS                               |                                  |                                  |                                  |                                  |                                  |
| Sex                              |                                  |                                  |                                  |                                  |                                  |
| Men                              | 1.004 (0.999–1.008)              | 1.001 (0.990–1.012)              | 0.997 (0.993–1.004)               | 0.987 (0.963–1.033)               | 1.003 (0.955–1.052)              |
| Women                            | 1.000 (0.993–1.007)              | 1.006 (0.989–1.022)              | 1.006 (0.954–1.061)               | 1.013 (0.981–1.047)               | 1.025 (0.953–1.102)              |
| Age group                        |                                  |                                  |                                  |                                  |                                  |
| <60 y                            | 1.004 (0.996–1.013)              | 0.999 (0.988–1.018)              | 1.004 (0.945–1.066)               | 0.967 (0.931–1.004)               | 1.021 (0.940–1.110)              |
| ≥60 y                            | 1.003 (0.998–1.009)              | 1.003 (0.989–1.016)              | 0.994 (0.952–1.038)               | 0.997 (0.971–1.024)               | 0.993 (0.936–1.054)              |
| IS                               | 1.006 (1.002–1.011)              | 1.003 (0.990–1.016)              | 0.990 (0.950–1.031)               | 0.970 (0.945–0.995)               | 0.965 (0.912–1.022)              |
| Sex                              |                                  |                                  |                                  |                                  |                                  |
| Men                              | 1.012 (1.006–1.017)              | 1.000 (0.983–1.018)              | 0.978 (0.925–1.033)               | 0.943 (0.911–0.977)               | 0.939 (0.869–1.015)              |
| Women                            | 1.002 (0.994–1.010)              | 1.005 (0.987–1.024)              | 1.003 (0.945–1.066)               | 1.000 (0.964–1.038)               | 0.996 (0.918–1.082)              |
| Age group                        |                                  |                                  |                                  |                                  |                                  |
| <60 y                            | 1.008 (0.997–1.019)              | 1.007 (0.981–1.033)              | 0.989 (0.912–1.072)               | 0.954 (0.907–1.004)               | 1.035 (0.926–1.156)              |
| ≥60 y                            | 1.007 (1.002–1.012)              | 1.001 (0.986–1.016)              | 0.990 (0.944–1.038)               | 0.975 (0.947–1.004)               | 0.943 (0.883–1.007)              |
| ICH                              | 0.995 (0.986–1.004)              | 0.999 (0.978–1.020)              | 1.017 (0.949–1.090)               | 1.036 (0.994–1.081)               | 1.113 (1.014–1.221)              |
| Sex                              |                                  |                                  |                                  |                                  |                                  |
| Men                              | 0.995 (0.984–1.007)              | 0.994 (0.968–1.021)              | 1.020 (0.934–1.113)               | 1.022 (0.969–1.078)               | 1.104 (0.981–1.243)              |
| Women                            | 0.993 (0.979–1.008)              | 1.006 (0.973–1.041)              | 1.013 (0.904–1.134)               | 1.060 (0.980–1.134)               | 1.127 (0.970–1.310)              |
| Age group                        |                                  |                                  |                                  |                                  |                                  |
| <60 y                            | 1.000 (0.988–1.012)              | 0.990 (0.962–1.018)              | 1.022 (0.932–1.120)               | 0.983 (0.929–1.041)               | 1.004 (0.885–1.139)              |
| ≥60 y                            | 0.985 (0.975–0.995)              | 1.030 (1.005–1.055)              | 1.006 (0.905–1.120)               | 1.106 (1.039–1.178)               | 1.262 (1.100–1.448)              |

AS indicates all stroke; CI, confidence interval; ICH, intracerebral hemorrhage; IS, ischemic stroke; NO$_2$, nitrogen dioxide; PM$_{10}$, particulate matter <10 mm in aerodynamic diameter; and RR, relative risk.

*P <0.05.
†P <0.001.
is needed, including the relationship between pollutants and stroke incidence in older persons.

There are several limitations and strengths to our single hospital-based study.

First, the main limitation of this study is that we still have not determined the proportion of patients who were treated outside our hospital; however, we think that the proportion of patients treated outside the hospital was relatively small. We excluded 3 dongs in this study because of their relative closeness to other tertiary hospitals to help mitigate this potential bias.

Second, the number of meteorologic and air pollution variables is limited. We initially set out to analyze the association

---

**Figure 1.** Odds ratios with 95% confidence intervals for seasonal incidence of stroke in spring, summer, and autumn compared with winter, as well as monthly incidence of stroke stratified by sex and age group relative to January in selected areas of the Seongdong district, Seoul, South Korea, 2004 to 2013.
Figure 2. Odds ratios with 95% confidence intervals for seasonal incidence of ischemic and hemorrhagic stroke in spring, summer, and autumn compared with winter, as well as monthly incidence of ischemic and hemorrhagic stroke stratified by sex and age group relative to January in selected areas of the Seongdong district, Seoul, South Korea, 2004 to 2013.
of stroke incidence with meteorologic parameters, including temperature (monthly mean, average maximum and minimum), monthly diurnal temperature range, average barometric pressure, and humidity. However, after initial examination, we recognized that many meteorologic parameters are related. Hence, we had to exclude several meteorologic parameters, but we think our selection of mean temperature, diurnal temperature range, and humidity as the 3 meteorologic parameters did not preclude the influence of other weather parameters because average maximum/minimum temperature and atmospheric pressure are closely related to mean temperature. In addition, the ultimate goal of this article was to determine whether there is monthly and seasonal variation in stroke incidence and to evaluate the association between stroke and meteorologic parameters. Hence, consideration of pollutants was deemed to be less important relative to the meteorologic factors.

Finally, the study covering region was small. Therefore, the hospital stroke attack rates reported in this study may not be as accurate as those reported from larger community-based studies, making the generalizability of this study limited. However, studies covering a large region have inevitable data inconsistency issues, as well as weather and environmental heterogeneity. For example, a study from Japan covering a large sampling area admitted regional differences in temperature.25 The authors described the mean temperature in Kagoshima City, which is located in the southern part of Japan, as 16.3°C in spring, 26.5°C in summer, 21.8°C in fall, and 9.2°C in winter. By contrast, the temperature in Tokyo, which is in the center of Japan, was 14.6°C, 25.7°C, 20.0°C, and 9.2°C in winter. By contrast, the temperature in Tokyo, Japan, as 16.3°C in spring, 26.5°C in summer, 21.8°C in fall, and 9.2°C in winter.25 The authors described the mean temperature in Kagoshima City, which is located in the southern part of Japan, as 16.3°C in spring, 26.5°C in summer, 21.8°C in fall, and 9.2°C in winter. By contrast, the temperature in Tokyo, which is in the center of Japan, was 14.6°C, 25.7°C, 20.0°C, and 9.2°C in winter. By contrast, the temperature in Tokyo, Japan, as 16.3°C in spring, 26.5°C in summer, 21.8°C in fall, and 9.2°C in winter.

The population density of Seoul is high, so we think this population was appropriate for studying seasonal and monthly variation in stroke. We also think it valuable to estimate the incidence of stroke under similar weather and environmental conditions in the specific area of our study. In addition, the data quality, consistency, and accuracy of our study are reliable because the authors were able to manage all data directly and consistently within a single hospital.

In conclusion, we have demonstrated distinct patterns of seasonal and monthly variation in the incidence of stroke and its subtypes with consideration of meteorologic and air pollution parameters. We found a significant trend toward higher IS incidence during summer and early autumn and higher hemorrhagic stroke attack rates in spring and winter. These trends were significantly correlated with mean temperature. Monthly variation in stroke was prominent in men and the older age group. Stroke incidence peaked in September; however, the biological mechanisms for this peak incidence remain unclear. We expect these findings to enhance our understanding of stroke and its association with weather and pollutants.

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**Disclosures**

None.

**References**


38. Tsai SS, Goggins WB, Chiu HF, Yang CY. Evidence for an association between air pollution and daily stroke admissions in Kaohsiung, Taiwan. *Stroke*. 2003;34:2612–2616. doi: 10.1161/01.STR.0000095564.33543.64.


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SUPPLEMENTAL MATERIAL

The effect of seasonal and monthly variation in weather and air pollution factors on stroke incidence in Seoul, Korea

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1Department of Neurosurgery, 2Department of Neurology, Hanyang University Medical center, Seoul, Korea

Supplemental data:
Tables I-VIII
Figures I and II
Supplemental Table I. Descriptive statistics for monthly weather variables in selected areas of the Seongdong District, Seoul, Korea, 2004-2013

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean (SD*)</th>
<th>IQR*</th>
<th>Min, Max</th>
<th>Mean (SD*)</th>
<th>IQR*</th>
<th>Min, Max</th>
<th>Mean (SD*)</th>
<th>IQR*</th>
<th>Min, Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>-2.54 (2.17)</td>
<td>2.50</td>
<td>-7.20, 0.40</td>
<td>21.41 (3.36)</td>
<td>5.52</td>
<td>18.10, 27.90</td>
<td>54.90 (4.95)</td>
<td>8</td>
<td>49, 65</td>
</tr>
<tr>
<td>Feb</td>
<td>0.56 (2.12)</td>
<td>3.83</td>
<td>-2.00, 4.00</td>
<td>25.44 (3.07)</td>
<td>5.68</td>
<td>20.60, 29.70</td>
<td>52.50 (5.04)</td>
<td>8</td>
<td>43, 59</td>
</tr>
<tr>
<td>Mar</td>
<td>5.31 (1.13)</td>
<td>1.90</td>
<td>3.60, 7.30</td>
<td>23.39 (2.65)</td>
<td>2.80</td>
<td>18.20, 28.20</td>
<td>53.30 (3.89)</td>
<td>6</td>
<td>49, 60</td>
</tr>
<tr>
<td>Apr</td>
<td>11.86 (1.49)</td>
<td>2.60</td>
<td>9.50, 14.10</td>
<td>22.17 (4.00)</td>
<td>5.35</td>
<td>14.70, 28.80</td>
<td>53.20 (1.55)</td>
<td>2</td>
<td>50, 55</td>
</tr>
<tr>
<td>May</td>
<td>18.16 (0.75)</td>
<td>0.90</td>
<td>17.20, 19.70</td>
<td>20.96 (2.45)</td>
<td>4.60</td>
<td>17.30, 23.90</td>
<td>58.40 (5.20)</td>
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</tr>
<tr>
<td>Jun</td>
<td>22.87 (0.97)</td>
<td>1.63</td>
<td>21.50, 24.40</td>
<td>17.84 (1.42)</td>
<td>2.20</td>
<td>15.90, 20.60</td>
<td>63.60 (4.50)</td>
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<td>54, 69</td>
</tr>
<tr>
<td>Jul</td>
<td>24.81 (0.80)</td>
<td>1.15</td>
<td>23.10, 25.80</td>
<td>13.54 (1.70)</td>
<td>2.78</td>
<td>10.80, 15.90</td>
<td>77.50 (2.99)</td>
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<td>74, 82</td>
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<tr>
<td>Aug</td>
<td>26.28 (0.83)</td>
<td>1.42</td>
<td>25.10, 27.70</td>
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<td>12.80, 19.10</td>
<td>71.80 (3.42)</td>
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<td>68, 78</td>
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<tr>
<td>Sep</td>
<td>21.63 (0.33)</td>
<td>0.40</td>
<td>21.00, 22.00</td>
<td>19.15 (2.51)</td>
<td>4.80</td>
<td>15.50, 23.00</td>
<td>65.80 (5.57)</td>
<td>10</td>
<td>58, 74</td>
</tr>
<tr>
<td>Oct</td>
<td>15.48 (1.06)</td>
<td>1.38</td>
<td>14.20, 17.90</td>
<td>21.85 (1.59)</td>
<td>3.00</td>
<td>19.60, 23.80</td>
<td>60.10 (3.54)</td>
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<td>54, 65</td>
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<tr>
<td>Nov</td>
<td>7.62 (1.57)</td>
<td>2.30</td>
<td>5.50, 10.70</td>
<td>24.20 (3.59)</td>
<td>4.90</td>
<td>18.70, 31.40</td>
<td>58.70 (3.83)</td>
<td>7</td>
<td>55, 66</td>
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<tr>
<td>Dec</td>
<td>-0.52 (2.18)</td>
<td>3.45</td>
<td>-4.10, 1.90</td>
<td>23.70 (2.73)</td>
<td>4.32</td>
<td>19.70, 28.60</td>
<td>56.60 (3.41)</td>
<td>5</td>
<td>51, 60</td>
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* SD, standard deviation; IQR, interquartile range
Supplemental Table II. Descriptive statistics for monthly air pollution in selected areas of the Seongdong District, Seoul, Korea, 2004-2013

<table>
<thead>
<tr>
<th>Month</th>
<th>PM$_{10}$* (µg/m$^3$)</th>
<th>IQR*</th>
<th>Min, Max</th>
<th>NO$_2$* (µg/m$^3$)</th>
<th>IQR*</th>
<th>Min, Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>64.4 (10.36)</td>
<td>10.25</td>
<td>47, 87</td>
<td>38.8 (6.56)</td>
<td>9.50</td>
<td>29, 51</td>
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<tr>
<td>Feb</td>
<td>67.8 (14.91)</td>
<td>28.50</td>
<td>46, 85</td>
<td>37.8 (6.63)</td>
<td>7.75</td>
<td>28, 52</td>
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<tr>
<td>Mar</td>
<td>62.2 (6.36)</td>
<td>7.25</td>
<td>48, 70</td>
<td>31.5 (8.76)</td>
<td>11.75</td>
<td>22, 49</td>
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<tr>
<td>Apr</td>
<td>67.2 (14.94)</td>
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<td>49, 101</td>
<td>35.0 (8.08)</td>
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<td>May</td>
<td>66.2 (11.72)</td>
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<td>53, 86</td>
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<td>8.00</td>
<td>23, 44</td>
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<td>Jun</td>
<td>49.4 (9.47)</td>
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<td>39, 73</td>
<td>29.1 (6.52)</td>
<td>7.00</td>
<td>15, 39</td>
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<tr>
<td>Jul</td>
<td>34.2 (5.83)</td>
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<td>26, 44</td>
<td>22.4 (5.54)</td>
<td>8.75</td>
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<tr>
<td>Aug</td>
<td>29.4 (6.64)</td>
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<td>16, 41</td>
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<tr>
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<td>23, 43</td>
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<td>Nov</td>
<td>51.7 (11.72)</td>
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<td>39, 73</td>
<td>35.1 (7.68)</td>
<td>11.25</td>
<td>28, 50</td>
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<tr>
<td>Dec</td>
<td>62.6 (10.55)</td>
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<td>44, 73</td>
<td>34.1 (8.61)</td>
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* PM$_{10}$, particulate matter less than 10 mm in aerodynamic diameter; NO$_2$, nitrogen dioxide; SD, standard deviation; IQR, interquartile range
<table>
<thead>
<tr>
<th></th>
<th>Mean temperature (°C)</th>
<th>Diurnal temperature range (°C)</th>
<th>Humidity (%)</th>
<th>PM₁₀* (μg/m³)</th>
<th>NO₂* (μg/m³)</th>
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<td>Diurnal temperature range (°C)</td>
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<tr>
<td>Humidity (%)</td>
<td>1.00</td>
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<td>-0.43</td>
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<tr>
<td>PM₁₀* (μg/m³)</td>
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<td></td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>NO₂* (μg/m³)</td>
<td></td>
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<td></td>
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<td>1.00</td>
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</table>

* PM₁₀, particulate matter less than 10 mm in aerodynamic diameter; NO₂, nitrogen dioxide
Supplemental Table IV. Odds ratios and 95% confidence intervals using binary logistic regression for stroke subtypes, stratified by sex and age group, based on 1°C increments in mean temperature and diurnal temperature range

<table>
<thead>
<tr>
<th></th>
<th>Mean temperature (°C)</th>
<th>Diurnal temperature range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR* (95% CI)</td>
<td>P</td>
</tr>
<tr>
<td>IS</td>
<td>1.011 (1.003-1.019)</td>
<td>0.007</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.015 (1.004-1.025)</td>
<td>0.006</td>
</tr>
<tr>
<td>Women</td>
<td>1.008 (0.995-1.021)</td>
<td>0.215</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 years</td>
<td>1.002 (0.990-1.014)</td>
<td>0.750</td>
</tr>
<tr>
<td>≥60 years</td>
<td>1.022 (1.010-1.033)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICH</td>
<td>0.989 (0.981-0.997)</td>
<td>0.007</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>0.986 (0.975-0.996)</td>
<td>0.006</td>
</tr>
<tr>
<td>Women</td>
<td>0.992 (0.980-1.005)</td>
<td>0.215</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 years</td>
<td>0.998 (0.986-1.010)</td>
<td>0.750</td>
</tr>
<tr>
<td>≥60 years</td>
<td>0.979 (0.968-0.990)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*OR of IS over ICH
†OR of ICH over IS
Supplemental Table V. Odds ratios and 95% confidence intervals using binary logistic regression for stroke subtypes, stratified by sex and age group, based on 10-μg/m³ increases in the PM$_{10}$ and NO$_2$

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$* (μg/m³)</th>
<th>OR* (95% CI)</th>
<th>P</th>
<th>NO$_2$* (μg/m³)</th>
<th>OR* (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>0.936 (0.892-0.981)</td>
<td>0.006</td>
<td></td>
<td>0.876 (0.793-0.967)</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>0.927 (0.871-0.987)</td>
<td>0.018</td>
<td></td>
<td>0.843 (0.744-0.955)</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>0.937 (0.869-1.010)</td>
<td>0.087</td>
<td></td>
<td>0.922 (0.784-1.085)</td>
<td>0.329</td>
<td></td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 years</td>
<td>0.977 (0.906-1.054)</td>
<td>0.547</td>
<td></td>
<td>1.028 (0.884-1.195)</td>
<td>0.717</td>
<td></td>
</tr>
<tr>
<td>≥60 years</td>
<td>0.885 (0.828-0.946)</td>
<td>&lt;0.001</td>
<td></td>
<td>0.776 (0.675-0.893)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>OR† (95% CI)</th>
<th>P</th>
<th>OR† (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICH</td>
<td>1.069 (1.019-1.121)</td>
<td>0.006</td>
<td>1.142 (1.035-1.260)</td>
<td>0.008</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.078 (1.013-1.148)</td>
<td>0.018</td>
<td>1.187 (1.048-1.344)</td>
<td>0.007</td>
</tr>
<tr>
<td>Women</td>
<td>1.068 (0.990-1.151)</td>
<td>0.087</td>
<td>1.084 (0.922-1.275)</td>
<td>0.329</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;60 years</td>
<td>1.024 (0.949-1.104)</td>
<td>0.547</td>
<td>0.973 (0.837-1.131)</td>
<td>0.717</td>
</tr>
<tr>
<td>≥60 years</td>
<td>1.130 (1.057-1.207)</td>
<td>&lt;0.001</td>
<td>1.288 (1.120-1.481)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*OR of IS over ICH
†OR of ICH over IS
Supplemental Table VI. Associations of mean temperature for an increase of 1°C with ischemic stroke incidence after adjusting for other variables in selected areas of the Seongdong District, Seoul, Korea, 2004-2013

<table>
<thead>
<tr>
<th>Mean temperature</th>
<th>Model 1† OR* (95% CI) P</th>
<th>Model 2‡ OR* (95% CI) P</th>
<th>Model 3§ OR* (95% CI) P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>1.012 (1.000-1.024) 0.057</td>
<td>1.012 (1.004-1.021) 0.003</td>
<td>1.015 (1.006-1.023) 0.001</td>
</tr>
<tr>
<td>Sex Men</td>
<td>1.017 (1.000-1.034) 0.051</td>
<td>1.020 (1.002-1.039) 0.027</td>
<td></td>
</tr>
<tr>
<td>Age group ≥60 years</td>
<td>1.015 (1.002-1.029) 0.023</td>
<td>1.013 (0.999-1.026) 0.061</td>
<td></td>
</tr>
</tbody>
</table>

*OR of IS over ICH
†Model 1 was adjusted for meteorologic variables (diurnal temperature range and humidity) and pollutants (PM$_{10}$, NO$_2$).
‡Model 2 was adjusted for the variables in model 1 plus history of hypertension, diabetes, smoking and alcohol consumption.
§Model 3 was adjusted for the variables in model 2 plus age and sex.
Supplemental Table VII. Associations of diurnal temperature range for an increase of 1°C with hemorrhagic stroke incidence after adjusting for other variables in selected areas of the Seongdong District, Seoul, Korea, 2004-2013

<table>
<thead>
<tr>
<th>Diurnal temperature range</th>
<th>Model 1†</th>
<th>Model 2‡</th>
<th>Model 3§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR* (95% CI)</td>
<td>P</td>
<td>OR* (95% CI)</td>
</tr>
<tr>
<td>ICH</td>
<td>0.994 (0.968-1.021)</td>
<td>0.668</td>
<td>0.993 (0.966-1.021)</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥60 years</td>
<td>1.010 (0.973-1.049)</td>
<td>0.586</td>
<td>1.011 (0.973-1.050)</td>
</tr>
</tbody>
</table>

*OR of ICH over IS
†Model 1 was adjusted for meteorologic variables (mean temperature and humidity) and pollutants (PM$_{10}$, NO$_2$).
‡Model 2 was adjusted for the variables in model 1 plus history of hypertension, diabetes, smoking and alcohol consumption.
§Model 3 was adjusted for the variables in model 2 plus age and sex.
Supplemental Table VIII. Associations of air pollutants for an increase of 10 μg/m³ with hemorrhagic stroke incidence after adjusting for other variables in selected areas of the Seongdong District, Seoul, Korea, 2004-2013

<table>
<thead>
<tr>
<th></th>
<th>Model 1†</th>
<th></th>
<th>Model 2‡</th>
<th></th>
<th>Model 3§</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR*(95% CI)</td>
<td>P</td>
<td>OR*(95% CI)</td>
<td>P</td>
<td>OR*(95% CI)</td>
<td>P</td>
</tr>
<tr>
<td>PM₁₀</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICH</td>
<td>1.044 (0.984-1.108)</td>
<td>0.158</td>
<td>1.039 (0.969-1.115)</td>
<td>0.282</td>
<td>1.038 (0.973-1.107)</td>
<td>0.256</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.042 (0.952-1.141)</td>
<td>0.374</td>
<td>1.012 (0.920-1.115)</td>
<td>0.800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥60 years</td>
<td>1.053 (0.964-1.150)</td>
<td>0.252</td>
<td>1.050 (0.958-1.149)</td>
<td>0.297</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICH</td>
<td>1.066 (0.942-1.207)</td>
<td>0.309</td>
<td>1.095 (0.973-1.232)</td>
<td>0.132</td>
<td>1.050 (0.918-1.200)</td>
<td>0.474</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.117 (0.964-1.293)</td>
<td>0.140</td>
<td>1.137 (0.975-1.327)</td>
<td>0.102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥60 years</td>
<td>1.176 (1.000-1.383)</td>
<td>0.050</td>
<td>1.220 (1.034-1.440)</td>
<td>0.019</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*OR of ICH over IS
†Model 1 was adjusted for meteorologic variables (diurnal temperature range and humidity) and each other pollutant.
‡Model 2 was adjusted for the variables in model 1 plus history of hypertension, diabetes, smoking and alcohol consumption.
§Model 3 was adjusted for the variables in model 2 plus age and sex.
Supplemental Figure I. Box-plot diagram showing the incidence of all stroke and its subtype classified by the quartile groups of mean temperature and diurnal temperature range during 10 years in selected areas of the Seongdong district, Seoul, South Korea, 2004–2013. Box plots show median values (solid horizontal line), 50th percentile values (box outline), outlier values (open circles) and extreme outlier values (asterisks).
Supplemental Figure II. Box-plot diagram showing the incidence of all stroke and its subtype classified by the quartile groups of pollutants during 10 years in selected areas of the Seongdong district, Seoul, South Korea, 2004–2013. Box plots show median values (solid horizontal line), 50th percentile values (box outline), and outlier values (open circles).
대한민국 서울에서 계절 및 월별 날씨 변이와 대기오염 인자가 뇌졸중 발생에 미치는 영향

Effect of Seasonal and Monthly Variation in Weather and Air Pollution Factors on Stroke Incidence in Seoul, Korea

Myung-Hoon Han, MD; Hyeong-Joong Yi, MD, PhD; Young-Soo Kim, MD, PhD; Young-Seo Kim, MD, PhD

(Stroke. 2015;46:927-935.)

Key Words: incidence ■ stroke ■ temperature

배경과 목적
본 연구의 목적은 뇌졸중 발생률에서 계절 및 월별 날씨 변이와 대기오염 인가의 대기오염에 따른 뇌졸중 발생률에서 계절 및 월별 날씨 변이와 대기오염 인가의 영향을 알아보는 것은 중요하다. 따라서 이러한 연구 결과를 통한 뇌졸중 예방 및 대기오염 관리에 대한 이해를 향상시키는 것을 기대할 수 있다.

방법
2004년 1월 1일부터 2013년 12월 31일 사이, 대한민국 서울 성동구라는 특정 지역에서 연속적으로 뇌졸중 사건이 빈번하게 발생하였다. 이는 연구자들은 매월 10,000명당 뇌졸중 사례 발생률과 기상학적 및 대기오염 매개변수에 대한 연구가 필요하다고 생각하였다. 또한, 계절 및 월별 뇌졸중 발생률에 대한 OR과 95% CI를 분석하였다.

결과
1월에 비해 9월의 뇌졸중 발생률이 유의하게 높았다(OR, 1.233; 95% CI, 1.042-1.468). 여름의 계절성 허혈뇌졸중 발생률(OR, 1.183, 95% CI, 1.056-1.345)은 겨울에 비해 유의하게 높았고, 그에 반해 겨울 뇌내출혈의 계절성 발생률은 유의한 차이가 없었다. 평균 연도는 허혈뇌졸중과 영의 관계를 보였고(RR, 1.006, 95% CI, 1.004-1.007), 이산화질소(RR, 1.262, 95% CI, 1.262-1.301)는 고령군에서 뇌내출혈 발생률과 강한 양의 관계를 보였다.

결론
이 연구는 기상학적 및 대기오염 매개변수를 고려한 뇌졸중 및 그 이상증 발생률에 계절 및 월별 변이가 두려한 양상을 보여주었다. 따라서 이러한 연구 결과를 통하여 뇌졸중 날씨 및 오염물 질 사이의 관계에 대한 이해를 향상시키는 것을 기대할 수 있다.

Table 4. Relative Risk and 95% Confidence Interval for All Stroke and Stroke Subtypes Stratified by Sex and Age Group, Based on 1°C Increments in Mean Temperature and Diurnal Temperature Range, 5% Increments in Humidity, and 10 μg/m3 Increases in Air Pollutants

<table>
<thead>
<tr>
<th>Metropolitan Variables</th>
<th>Air Pollution Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Temperature, °C</td>
<td>Humidity, %</td>
</tr>
<tr>
<td>RR (95% CI)</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>AS</td>
<td>1.004 (0.999-1.008)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1.007 (1.000-1.013)†</td>
</tr>
<tr>
<td></td>
<td>1.000 (0.993-1.007)</td>
</tr>
<tr>
<td>Women</td>
<td>1.006 (0.986-1.022)</td>
</tr>
<tr>
<td>Age group</td>
<td>1.004 (0.996-1.013)</td>
</tr>
<tr>
<td>&lt;60 y</td>
<td>1.003 (0.998-1.019)</td>
</tr>
<tr>
<td>≥60 y</td>
<td>1.006 (1.002-1.011)*</td>
</tr>
<tr>
<td>IS</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>1.012 (1.006-1.017)†</td>
</tr>
<tr>
<td>Women</td>
<td>1.002 (0.994-1.010)</td>
</tr>
<tr>
<td>Age group</td>
<td>1.008 (0.997-1.019)</td>
</tr>
<tr>
<td>&lt;60 y</td>
<td>1.007 (0.992-1.012)*</td>
</tr>
<tr>
<td>≥60 y</td>
<td>0.995 (0.986-1.004)</td>
</tr>
<tr>
<td>ICH</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>0.995 (0.984-1.007)</td>
</tr>
<tr>
<td>Women</td>
<td>0.993 (0.979-1.008)</td>
</tr>
<tr>
<td>Age group</td>
<td>1.000 (0.998-1.012)</td>
</tr>
<tr>
<td>&lt;60 y</td>
<td>0.985 (0.975-0.995)*</td>
</tr>
<tr>
<td>≥60 y</td>
<td>1.030 (1.005-1.055)*</td>
</tr>
</tbody>
</table>

AS indicates all stroke; CI, confidence interval; ICH, intracerebral hemorrhage; IS, ischemic stroke; NO_{2}, nitrogen dioxide; PM_{10}, particulate matter <10 mm in aerodynamic diameter; and RR, relative risk.

*P<0.05.  †P<0.001.