Serial Changes in Focal Hyperemia Associated With Hypertensive Putaminal Hemorrhage

Ryuta Suzuki, MD, Kikuo Ohno, MD, Yoshiharu Matsushima, MD, and Yutaka Inaba, MD

Seventeen separate xenon-enhanced computed tomographic images were performed in seven patients with hypertensive putaminal hemorrhage. Regional cerebral blood flow maps were then computed and assessed. All patients were categorized as being of good recovery potential, with moderate-sized hematomas, and all were treated conservatively. The regional cerebral blood flow assessments were scheduled within 4 days after, 2 weeks after, and >25 days after the ictus. The initial decrease in hemispheric blood flow ipsilateral to the side of the hematoma was calculated as the ratio of ipsilateral to contralateral hemispheric blood flow and was correlated with the size of the hematoma; that is, the larger the hematoma, the greater the decrease in the ratio of ipsilateral to contralateral hemispheric blood flow. The decrease persisted for 1 month. The mean of the ratio at 2 weeks after onset was 70%, the lowest during follow-up. All cases examined within 4 days after onset demonstrated perihematomatous focal hyperemia, or “luxury perfusion,” which accounted for the delayed decrease. The same tissue that had previously shown hyperemia showed decreased regional cerebral blood flow 2 weeks after onset. Our results demonstrate that the luxury perfusion syndrome caused the secondary brain damage even in the cases that were in relatively good condition. The feasibility of treatment can be assessed by considering these results. (Stroke 1988;19:322-325)

Treatment of hypertensive putaminal hemorrhage (HPH) has long been controversial.1,4 The primary brain damage caused by the hematoma is completed shortly after onset and cannot be repaired but can only be treated prophylactically. Patients suffering from HPH, however, have later deteriorated clinically.2,5 This subsequent worsening may be caused by secondary brain damage due to brain edema, cerebral ischemia, and increased intracranial pressure.5-8 The aim of treatment is to prevent or minimize secondary brain damage. For this purpose, it is important to recognize all pathophysiologic aspects of HPH. It has been suggested that there is “luxury perfusion” surrounding the intracerebral hematoma and that this phenomenon may be crucial to secondary brain damage.5,4 Regional cerebral blood flow (rCBF) and/or cerebral metabolism in hypertensive intracerebral hemorrhage (HIH) have been studied by several authors.6-8,13 However, only a few have demonstrated focal hyperemia or luxury perfusion.4-11 The purpose of our study was to clarify factors relating to the occurrence and timing of focal hyperemia, restricted to cases of HPH with moderate-sized hematomas, using serial topographic rCBF maps obtained by xenon-enhanced computed tomography (Xe-CT).

Subjects and Methods

From April 1984 to August 1985, 17 Xe-CT scans were made among seven patients with HPH. The patients comprised five men and two women with a mean age at onset of 58 years. Their clinical grades were either 1 or 2 according to the Japanese neurologic grading system for HIH,4 and their CT grades were 1 or IIIa according to the Japanese CT classification for HPH.4 The size of hematomas varied from 2.5 x 1.5 to 5 x 3.5 cm. All patients were treated medically, and all were able to walk unaided at the completion of their treatment. Follow-up Xe-CT rCBF measurements were planned at 1-4 days, at around 2 weeks, and at >1 month after onset. There were some practical limitations that modified this plan, so we performed Xe-CT in five patients within 4 days after onset (early period), in all patients between 12 and 17 days after onset (intermediate period), and in five patients between 25 days and 6 months after onset (late period). A summary of the cases is shown in Table 1.

Xe-CT was performed according to methods described by Suzuki et al.4 Patients received atropine sulfate subcutaneously before examination. After the baseline CT image was obtained, the patient inhaled a mixture of 40–50% xenon in oxygen for 3–4 minutes. During xenon inhalation, a series of 9-second CT scans were performed at 60-second intervals using a TCT60A scanner (Toshiba Corp., Tokyo, Japan).

rCBF values were derived from the following formulas: $K = \frac{C(T) - C(0)}{Q(T) - Q(0)} = \frac{[fL_1C_1(t)dt]}{L_1C(t)dt}$ and $f = 100 LK$, where $C$ and $C_1$ are the tissue and arterial blood xenon concentrations, respectively, converted to Hounsfield units (HU), $K$ is the tissue buildup flow rate constant, $f$ is the blood flow in the region of interest (in milliliters per 100 grams brain per minute), and $L$ or $\lambda$ is the tissue-blood partition coefficient, fixed at 0.9 according to the calculated $\lambda$ for gray matter using the Xe-CT method.15 The increase in the saturation of xenon in arterial blood ($C_A$) has been calculated by the modified Kelcz’s formulas$^{14,16}$ using
the patient's hematocrit and the Ostwald constant for xenon or obtained from direct CT scan of arterial blood. rCBF values for each voxel were converted into HU, and a topographic rCBF map was constructed.

Results
Physiologic variables for the patients during Xe-CT are shown in Table 2. Mean arterial blood pressure in the early period was slightly higher than that during the intermediate and late periods; otherwise, no differences were noted. The mean percentile ratios of hemispheric blood flow for the sides ipsilateral and contralateral to the hematoma (HFI: HFC) were 79% in the early period, 70% in the intermediate period, and 80% in the late period. In the early period, the larger the hematoma, the lower HFI: HFC; the ratio was 58% in Case 2 and 90% in Case 6. HFI: HFC was lowest in cases examined during the intermediate period, and there was a tendency for cases with larger hematomas to show a greater decrease in HFI than those with smaller hematomas. In the late period, HFI: HFC varied between cases although they still showed low HFI: HFC ratios, except for the case with the smallest hematoma. The chronologic changes in HFI: HFC are shown in Table 2.

The topographic rCBF maps showed hematomas as areas of very low perfusion partly surrounded by hyperemic zones in all cases examined during the early period (Figures 2 and 3). The hyperemic zones were next and mostly lateral to the hematomas and were confirmed as isodensity areas in CT images. The sizes of the hyperemic areas varied between cases. The most notable finding of our study was that those areas showing hyperemia in the early period changed into areas with low perfusion during the intermediate period, so that the areas with low perfusion fused to include both the hematomas and the areas of previous hyperemia. No case examined during the intermediate period showed areas of hyperemia. In the intermediate period plain CT revealed absorption of the hematoma plus slight brain edema. However, no changes in density in those previously hyperemic areas were seen (Figures 2 and 3). During the late period no case showed focal hyperemia; however, the extent of areas of low perfusion varied because of the different sizes of the hematomas and different follow-up intervals. Serial topographic rCBF maps of two cases are shown in Figures 2 and 3.

Discussion
In our study, the Xe-CT method for measuring rCBF was used. The method is efficient because of its excellent spatial resolution. Furthermore, we could easily correlate blood flow in a particular region and the CT appearance of the corresponding tissue by recalling the baseline CT image. However, the short inhalation interval could not supply accurate λ, so we chose λ = 0.9 for gray matter according to the direct measurement of λ by Segawa et al using the Xe-CT method with long inhalation. Since other methods for measuring rCBF (such as positron emission tomography, single photon emission tomography, etc.) have calculated rCBF by using predetermined λ, the method we used can be accepted as the alternative method for Xe-CT.

Our study clearly demonstrates that focal hyperemia occurred in the tissue next to the hematoma in patients with HPH. The phenomenon took place very soon after onset and contributed to secondary brain damage during the next 2-3 weeks. This phenomenon is clearly luxury perfusion. We have focused on patients with HPH and cases with hematomas of moderate size because treatment of these cases is controversial. We have shown that all cases presented with focal hyperemia and that the hyperemic tissues resulted in ischemic tissues as judged by later rCBF measurements. Thus, luxury perfusion appears responsible for

<table>
<thead>
<tr>
<th>Case/age/sex</th>
<th>Clinical grade</th>
<th>Side</th>
<th>CT grade</th>
<th>Size</th>
<th>Outcome</th>
<th>Early</th>
<th>Intermediate</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/62/M</td>
<td>1</td>
<td>Right</td>
<td>I</td>
<td>2 × 2 cm</td>
<td>100</td>
<td>—</td>
<td>11</td>
<td>35</td>
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<tr>
<td>2/55/M</td>
<td>2</td>
<td>Left</td>
<td>IIIa</td>
<td>5 × 3.5 cm</td>
<td>70</td>
<td>1</td>
<td>12</td>
<td>—</td>
</tr>
<tr>
<td>3/50/F</td>
<td>1</td>
<td>Right</td>
<td>IIIa</td>
<td>3 × 3 cm</td>
<td>80</td>
<td>3</td>
<td>16</td>
<td>—</td>
</tr>
<tr>
<td>4/72/F</td>
<td>1</td>
<td>Right</td>
<td>I</td>
<td>5 × 2 cm</td>
<td>70</td>
<td>3</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>5/64/M</td>
<td>1</td>
<td>Right</td>
<td>I</td>
<td>3 × 2.5 cm</td>
<td>80</td>
<td>3</td>
<td>12</td>
<td>180</td>
</tr>
<tr>
<td>6/64/M</td>
<td>1</td>
<td>Right</td>
<td>IIIa</td>
<td>2.5 × 1.5 cm</td>
<td>80</td>
<td>4</td>
<td>13</td>
<td>25</td>
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<tr>
<td>7/50/M</td>
<td>2</td>
<td>Right</td>
<td>IIIa</td>
<td>5 × 3 cm</td>
<td>80</td>
<td>—</td>
<td>12</td>
<td>31</td>
</tr>
</tbody>
</table>

CT, computed tomography; Xe-CT, xenon-enhanced CT; M, male; F, female. Clinical and CT grades evaluated according to Japanese classification of neurologic and CT grades in hypertensive putaminal hemorrhage. Outcome evaluated by Karnofsky rating.

Table 1. Clinical Summary of Seven Cases With Hypertensive Putaminal Hemorrhage

<table>
<thead>
<tr>
<th>Case/age/sex</th>
<th>Clinical grade</th>
<th>Side</th>
<th>CT grade</th>
<th>Size</th>
<th>Outcome</th>
<th>Follow-up Xe-CT (days after onset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/62/M</td>
<td>1</td>
<td>Right</td>
<td>I</td>
<td>2 × 2 cm</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>2/55/M</td>
<td>2</td>
<td>Left</td>
<td>IIIa</td>
<td>5 × 3.5 cm</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>3/50/F</td>
<td>1</td>
<td>Right</td>
<td>IIIa</td>
<td>3 × 3 cm</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>4/72/F</td>
<td>1</td>
<td>Right</td>
<td>I</td>
<td>5 × 2 cm</td>
<td>70</td>
<td>3</td>
</tr>
<tr>
<td>5/64/M</td>
<td>1</td>
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<td>I</td>
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<td>4</td>
</tr>
<tr>
<td>7/50/M</td>
<td>2</td>
<td>Right</td>
<td>IIIa</td>
<td>5 × 3 cm</td>
<td>80</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 2. Physiologic Parameters at Xenon-Enhanced Computed Tomography in Cases With Hypertensive Putaminal Hemorrhage During Each Follow-up Period

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Early (1-4 days)</th>
<th>Intermediate (11-16 days)</th>
<th>Late (25-180 days)</th>
</tr>
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<tbody>
<tr>
<td>Mean arterial blood pressure (mm Hg)</td>
<td>112 ± 8</td>
<td>102 ± 13</td>
<td>101 ± 7</td>
</tr>
<tr>
<td>PacO2 (mm Hg)</td>
<td>38.6 ± 4.9</td>
<td>36.0 ± 3.0</td>
<td>36.3 ± 3.3</td>
</tr>
<tr>
<td>HFI: HFC (%)</td>
<td>79 ± 13</td>
<td>70 ± 20</td>
<td>80 ± 19</td>
</tr>
</tbody>
</table>

Values are mean ± SD. HFI, hemispheric blood flow in side ipsilateral to hematoma; HFC, hemispheric blood flow in side contralateral to hematoma.
later clinical deterioration.\textsuperscript{5,6} Later deterioration was confirmed by our findings that HFI/ HFC was lowest 2–3 weeks after onset and this minimum coincided with the maximum intracranial pressure and maximum brain edema.\textsuperscript{6,7} Our study demonstrated that the initial CBF deterioration correlated with the size of the hematoma, as was reported in another longitudinal follow-up study of HIH by Ishii et al\textsuperscript{a} and in an animal model.\textsuperscript{19}

The luxury perfusion syndrome, which was first described by Lassen,\textsuperscript{18} has been observed in ischemic stroke.\textsuperscript{19,20} The phenomenon has been reported in many other cerebral disorders, including nontraumatic intracerebral hemorrhage.\textsuperscript{21,22} However, the occurrence of...
luxury perfusion in HIH remains unclear because the phenomenon is short-lived and may occur in a limited manner depending on the size and location of the hematoma. If studies were designed to take these conditions into account, results would be more definite, such as those of our study. The clinical significance of the hyperemia is still uncertain. However, as Lassen suggested, because luxury perfusion may be caused by local brain acidosis, acidosis itself may cause tissue injury. Recent investigations suggest that hyperemia opens the blood–brain barrier, and it causes secondary brain edema. As we demonstrated, this vicious cycle may result in ischemia in the hyperemic tissue injury. Recent investigations suggest that hyperemia opens the blood–brain barrier, and it causes secondary brain edema. As we demonstrated, this vicious cycle may result in ischemia in the hyperemic tissue injury. Recent investigations suggest that hyperemia opens the blood–brain barrier, and it causes secondary brain edema. As we demonstrated, this vicious cycle may result in ischemia in the hyperemic tissue injury.

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References


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