Postoperative Luxury Perfusion Syndrome in Patients with Severe Subarachnoid Hemorrhage Treated by Early Aneurysmal Clipping

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Abstract

Cerebral blood flow (CBF) was measured in 90 patients who underwent early aneurysmal clipping after subarachnoid hemorrhage (SAH). Measurements were made by a noninvasive, two-dimensional method involving intravenous injection of $^{133}$Xe. Patients of Hunt and Hess grades I and II exhibited normal to slightly subnormal CBF, without significant changes, during the study period. Grades III-V patients had almost normal CBF in the early postoperative period, but their CBF gradually decreased, becoming significantly low after day 31. It is noteworthy that in grades IV and V patients, CBF was abnormally high in the acute stage, relative to their poor neurological condition; these patients were considered to have the "global luxury perfusion syndrome." The syndrome was not uncommon in patients with severe SAH. Possible causative or contributory factors are attempts to surgically reduce intracranial pressure, which leads to increased cerebral perfusion pressure, and concomitant global dysautoregulation. In patients with this syndrome, maneuvers intended to increase CBF should be avoided, as they may aggravate brain swelling or cause hemorrhagic events. Positron emission tomographic studies will provide more accurate and useful information concerning the management of SAH patients.

Key words: cerebral blood flow, intracranial aneurysm, luxury perfusion syndrome, subarachnoid hemorrhage

Introduction

In recent years, early surgery for aneurysms producing subarachnoid hemorrhage (SAH) has gained acceptance as the treatment of choice. However, assessment of the pathophysiological status of patients with severe SAH is very difficult because of their precarious clinical condition. Measurement of cerebral blood flow (CBF) is one method used for such assessment, and many have studied CBF following rupture of intracranial aneurysms. However, there have been no reports of large-scale studies of CBF changes following early aneurysm surgery and including cases of severe SAH. The present study was designed to assess postoperative CBF in such cases.

CBF was measured by a noninvasive, two-dimensional method. Abnormally high CBF values, relative to the neurological status, were obtained after early surgery for severe SAH. In the present study, special attention was paid to this phenomenon, termed the "luxury perfusion syndrome," and its relevance to the management of SAH.

Patients and Methods

The study population comprised 90 SAH patients treated by early aneurysm surgery in 1984 and 1985. There were 49 females and 41 males ranging in age from 20 to 75 years (mean ± SD, 55 ± 10 years). The aneurysms were located in the anterior communicating artery (AcomA) in 43, the internal...
carotid artery (ICA) in 22, and the middle cerebral artery (MCA) in 25 cases. They were clipped within a maximum of 72 hours after the onset of SAH in all cases, and 74 cases (82%) within 24 hours. Patients were graded preoperatively according to the system of Hunt and Hess. Depending on the clinical status, emplacement of a ventricular drainage catheter (Dow Corning K.K., Kanagawa, Japan), external decompression, and/or evacuation of an intracerebral hematoma (ICH) were also carried out.

CBF was measured by the $^{133}$Xe intravenous injection method with a BI-1400 Regional CBF Analyzer (Valmet Oy Instrument Work, Tempea, Finland). After injection of 10 mCi of $^{133}$Xe into the antecubital vein, the $^{133}$Xe clearance curve was monitored for 10 minutes and fast flow, slow flow, and the initial slope index (ISI) were calculated. The ISI was used as the CBF value in patients with unstable flow compartments, as recommended by Risberg et al. In cases of ICA and MCA aneurysms, the mean of 14 ISI values in the affected hemisphere was used as the CBF value. CBF was measured postoperatively from one to seven times (mean, three times) in each patient. The total number of CBF measurements in all patients was 283. Arterial blood gas analyses and blood pressure (BP) measurements were obtained immediately after each CBF measurement.

The routine postoperative management included administration of 200 ml of glycerol (Glyceol) b.i.d. or t.i.d. for 1–2 weeks and administration of 500 ml of low molecular weight dextran for vasospasm and maintenance of normovolemia. Therapeutic hypertension was not applied during the study period. In cases of controlled ventricular drainage without external decompression, intracranial pressure (ICP) exceeding 30 mmHg was controlled by intermittent drainage. In cases of external decompression and/or in the event of moderate to severe vasospasm, drainage was continuous until the vasospasm resolved. Permanent shunts were installed in patients whose neurological status deteriorated due to hydrocephalus during days 15–30.

Data obtained from 30 healthy volunteers 26–60 years of age (mean ± SD, 41 ± 11 years) were used as reference CBF values. Their mean ISI was 52 ± 6. Statistical analysis was by Student’s t-test. Values are expressed as means ± SD.

Results

I. Preoperative grade and ICH

The preoperative grades and the incidence of ICH are shown in Table 1. The incidence of ICH was 0% among patients of grades I and II and was highest among those of grade IV.

II. Preoperative grade and operative procedure

Table 2 lists the preoperative grades and operative procedures employed. Decisions to perform controlled ventricular drainage and external decompression were based on the principles established by Ito. The worse the preoperative grade, the higher the frequency of these procedures. The rate of ICH evacuation was highest in grade IV cases.

III. Preoperative grade and postoperative CBF changes

Postoperative CBF changes, grouped by preoperative grade, are shown in Fig. 1. In patients of grades I and II, CBF was normal to slightly below normal, and did not significantly change throughout the postoperative course. Among grade III patients, the mean CBF was 49 ± 9 within day 3 and gradually decreased to 36 ± 8 after day 31; the reduction was significant (p < 0.001). In grade IV patients, CBF was almost normal within 14 days after SAH.
and gradually decreased to 36 ± 6 after day 31, which was significantly lower than the early postoperative CBF of 50 ± 11 (p < 0.01). In the 11 grade V cases, CBF was 54 ± 9 within 3 days after SAH, which was normal to slightly higher than normal and was the highest of all groups. This high CBF gradually decreased, reaching 32 ± 4 after day 31 (p < 0.001). Three grade V patients recovered, whereas seven became vegetative and one died. Within 30 days after SAH, it was difficult to predict the outcome on the basis of CBF values. After day 31, however, mean CBF was higher in those who recovered (41 ± 4) than in the vegetative survivors (29 ± 3) and was well correlated with the neurological status.

The clinical status of grades IV and V patients was definitely worse than their CBF values indicated in the acute stage after early aneurysm surgery. Some grade III patients also had higher CBF than their neurological status suggested, but this tendency was more prominent in patients of grades IV and V.

The results of blood gas analyses and the systolic BP data, shown in Table 3, revealed a tendency for BP to be slightly elevated and PaO2 and PaCO2 to be slightly low in the acute stage.

### IV. CBF changes and outcome

The CBF changes shown in Fig. 1 do not reflect the long-term postoperative courses. The outcome of early aneurysm surgery 6 months after SAH was evaluated by means of the Glasgow Outcome Scale (GOS), and the results are given in Table 4. It is clear that patients with poor outcomes had worse preoperative grades. Among those of grades I–III, vasospasm was the major cause of disability and death. On the other hand, in patients of grades IV and V, preoperative brain injury due to rupture of the aneurysm was the cause of the poor outcomes. Good recovery or moderate disability was observed in 95% of grades I and II, 87% of grade III, 64% of grade IV, and 27% of grade V patients.

The GOS scores at 6 months and the postoperative CBF changes are presented in Fig. 2. Patients who showed good recovery (a GOS score of 5) did not show significant CBF changes early after surgery; their CBF values were normal to slightly lower than those of the normal volunteers. In those with moderate disability (a score of 4), mean CBF was normal to slightly subnormal within 14 days after SAH and decreased to 35 ± 5 after day 31, which was significantly lower than the CBF within day 7 of 45 ± 10 (p < 0.001). Severely disabled patients (a score of 3) exhibited a CBF pattern similar to that of the GOS 4 group until after day 31, at which time their CBF decreased to 29 ± 3. The cause of this change was either extensive hemispheric damage due to massive ICH or severe vasospasm. Patients who lapsed into a persistent vegetative state (a score of 2) underwent a gradual decrease in CBF, from 45 ± 9 within day 7 to 32 ± 5 after day 31. There were one grade IV patient and seven grade V patients in this group, and diffuse preoperative brain damage due to SAH was the cause of their vegetative survival. The patients who died (a score of 1) also showed a gradual decrease in CBF, but their small number...
Table 3: Preoperative grade and time course changes of arterial blood gas analyses and systolic BP

<table>
<thead>
<tr>
<th>Day after SAH</th>
<th>Preoperative grade</th>
<th>pH</th>
<th>PaO₂ (mmHg)</th>
<th>BP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I and II</td>
<td>III</td>
<td>IV</td>
<td>V</td>
</tr>
<tr>
<td>1-3</td>
<td>7.447 ± 0.027</td>
<td>7.460 ± 0.026</td>
<td>7.457 ± 0.012</td>
<td>7.458 ± 0.051</td>
</tr>
<tr>
<td>4-7</td>
<td>7.457 ± 0.026</td>
<td>7.467 ± 0.061</td>
<td>7.462 ± 0.038</td>
<td>7.487 ± 0.029</td>
</tr>
<tr>
<td>8-14</td>
<td>7.449 ± 0.026</td>
<td>7.454 ± 0.027</td>
<td>7.442 ± 0.033</td>
<td>7.465 ± 0.034</td>
</tr>
<tr>
<td>15-30</td>
<td>7.428 ± 0.032</td>
<td>7.432 ± 0.026</td>
<td>7.436 ± 0.024</td>
<td>7.483 ± 0.027</td>
</tr>
<tr>
<td>31≤</td>
<td>7.422 ± 0.026*</td>
<td>7.422 ± 0.038*</td>
<td>7.418 ± 0.022**</td>
<td>7.437 ± 0.039</td>
</tr>
</tbody>
</table>

*After Hunt and Hess

Table 4: Preoperative grade and outcome 6 months after SAH

<table>
<thead>
<tr>
<th>GOS score</th>
<th>No. of cases</th>
<th>Preoperative grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I and II</td>
<td>III</td>
</tr>
<tr>
<td>5</td>
<td>48 (33)</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>24 (5)</td>
<td>7 (2)</td>
</tr>
<tr>
<td>3</td>
<td>5 (3)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>5 (3)</td>
<td>1 (1)</td>
</tr>
</tbody>
</table>

*GOS 5: good recovery, 4: moderate disability, 3: severe disability, 2: persistent vegetative state, 1: death

Discussion

In 1971, Gordon et al. in describing a comatose SAH patient whose CBF was abnormally high, used the term “global luxury perfusion.” In 1975, Sakurai and colleagues reported two cases of severe SAH with the global luxury perfusion syndrome and angiographic evidence of severe vasospasm and early venous filling. Weir et al. also noted high CBF in patients whose clinical status was poor. Gelmers et al. observed hyperemic areas in SAH patients and regarded the phenomenon as a reaction to initial ischemia. Although the global luxury perfusion syndrome following SAH is generally considered a rare phenomenon, the results of this study, which is perhaps the first in which CBF was measured after early aneurysm surgery in a large number of patients, suggest that postoperative global luxury perfusion is not uncommon in patients with severe SAH.

The concept of the luxury perfusion syndrome was first advanced by Lassen in 1966. He assumed that metabolic acidosis consequent to brain hypoxia accompanied by diminished or absent “autoregulation” was the most likely explanation for this syndrome. Gordon and coworkers proposed that intracerebral metabolic acidosis and impaired capillary circulation, which results in the diminution of brain metabolism, is the pathophysiological background of the luxury perfusion syndrome. Sakurai et al. cited diffuse vasoparalysis due to cerebral ischemia after SAH, along with increased cerebral perfusion pressure (CPP), as the cause of global luxury perfusion and commented that this syndrome is ominous in terms of prognosis.

In the acute stage of severe SAH, CPP is markedly reduced due to elevated ICP. Cerebral vascular reactivity is also disturbed, globally or focally, in proportion to the severity of SAH. Surgical procedures to reduce ICP, such as ventricular drainage, external decompression, and/or ICH evacuation, will increase CPP. Elevation of CPP can, in turn, increase CBF in severe SAH, due to coexisting dysautoregulation. In this study, cerebral...
metabolism was not examined. However, in patients with severe SAH who did not show neurological recovery after early surgery, postoperative CBF was abnormally high given their neurological status, and this condition was assumed to be global luxury perfusion. The abnormally high CBF of these patients progressively decreased during the first month after SAH and reached an adequately low level after the second month. The degree of postoperative luxury perfusion may depend upon the extent of dysautoregulation and the effectiveness of surgical attempts to reduce ICP.

In cases in which CBF increased with concomitant neurological improvement after early aneurysm surgery, impairment of brain function due to increased ICP might have been reversible preoperatively. It seems probable that these patients were in a state of "misery perfusion" and had had ischemic penumbral preoperatively. In this study, it was impossible to ascertain whether the postoperative CBF was "luxury," "misery," or "coupled." Within 3 days after SAH, patients with poorer preoperative grades tended to have higher CBF (Fig. 1), which may reflect global or focal luxury perfusion, even in patients who eventually recovered.

The effect of aneurysm surgery on CBF is controversial. Ferguson et al. and Nilsson reported a CBF decrease, whereas Weir et al. found a CBF increase, after surgery. In other investigations as well, postoperative CBF changes have varied. Mickey et al., using single photon emission computed tomography, found cortical ischemic areas produced by the operative procedure even in patients with good clinical outcomes. These differences may be attributable to differences in the timing of surgery, the surgical procedure employed, the degree of preoperative brain damage, and the method of CBF measurement.

In this study, CBF could not be measured preoperatively because surgery was performed on an emergency basis, but it is unlikely that there were substantial CBF changes after surgery in grades I and II patients. In grades III-V patients with preserved brain function, CBF increased in parallel with neurological improvement, although these patients may have had relative or focal hyperemia. In grades IV and V patients with severe brain damage and global dysautoregulation, CBF increased markedly when ICP was reduced surgically. These patients showed no neurological improvement, and their pathophysiological state was considered to be the global luxury perfusion syndrome.

In patients of preoperative grades I and II, most of whom enjoyed good recovery, CBF was normal to slightly below normal and did not fluctuate significantly after surgery. On the other hand, CBF decreased gradually during the first month after SAH and was significantly lower after the second month in grades III-V patients who were moderately disabled to vegetative (Figs. 1 and 2). These results

Fig. 2 Relationship between postoperative CBF changes and outcome at 6 months, as evaluated by the GOS. Patients who showed good recovery (GOS 5) did not manifest significant CBF changes. Moderate (GOS 4) and severe disability (GOS 3) were associated with a significant decrease in CBF after post-SAH day 15. Almost all GOS 3 patients suffered severe hemispheric damage due to ICH or vasospasm and had the lowest CBF values after day 31. Vegetative survivors (GOS 2) and patients who died (GOS 1) showed a gradual CBF decrease. The shaded areas represent the normal CBF range of 52 ± 6. *p < 0.05, **p < 0.01, ***p < 0.001, compared with the first week. N: number of patients, n: number of measurements.
suggest that CBF is reduced in proportion to the severity of the SAH. Meyer et al.\textsuperscript{21} also meticulously documented the gradual decrease in CBF after SAH. However, the mechanism of the reduction is unknown. In the series reported here, despite efforts to reduce ICP, CBF decreased gradually in grades III–V patients and was slightly below normal even in grades I and II patients.

Early postoperative luxury perfusion is one possible cause of gradually reduced CBF in patients of grades III–V. Other contributing factors include reduced cerebral metabolism due to SAH\textsuperscript{10,36} and, in some cases, vasospasm.\textsuperscript{5,7,10,14,36,39} The ‘‘no-reflow phenomenon,’’ which occurs immediately after aneurysmal rupture and disturbs the microcirculation, is also an important consideration. Asano and Sano\textsuperscript{31} confirmed the existence of no-reflow phenomenon in experimental SAH and stressed its importance in influencing the prognosis of SAH patients. The no-reflow phenomenon may in fact be involved in the slight CBF decrease seen even in mild SAH; the degree to which it occurs may affect the extent of luxury perfusion after early surgery and the ensuing CBF decrease in patients with moderate to severe SAH.

Early surgery following aneurysmal rupture has gained acceptance as the treatment of choice,\textsuperscript{4,16,34,40,41} except in severe SAH, for which the indications for early surgery are still under debate. Preoperatively, it is often very difficult to determine the likelihood of recovery. Suzuki et al.\textsuperscript{35} recommended ventricular drainage for severe SAH, followed, if successful, by radical surgery. I also follow this strategy for comatose SAH patients without a compressive hematoma, performing surgery as soon as possible after their initial recovery. In severe SAH patients treated by early surgery, the possibility of postoperative luxury perfusion syndrome must be kept in mind. If this should occur, attempts to increase CBF, such as hypertension-hypervolemic therapy,\textsuperscript{2,20} will raise the CPP and aggravate brain swelling, creating the additional danger of hemorrhagic infarction.\textsuperscript{29}

This study involved noninvasive, two-dimensional CBF measurement without metabolic evaluation. I believe, however, that these results support the existence of the luxury perfusion syndrome in severe SAH patients treated by early aneurysm surgery and measures to reduce ICP. Positron emission tomography, which can measure CBF and brain metabolism simultaneously and display the results three-dimensionally, will soon be used to investigate the pathophysiology of luxury perfusion syndrome in more detail. Identification of the CBF pattern as ‘‘luxury,’’ ‘‘misery,’’ or ‘‘coupled’’ is important in choosing appropriate therapy for SAH.

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References


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