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BACKGROUND AND PURPOSE: Cerebral hyperperfusion syndrome has been increasingly reported as a complication of carotid angioplasty and stent placement. The aim of the present study was to determine significant predictors of hyperperfusion phenomenon after carotid angioplasty and stent placement.

METHODS: We retrospectively reviewed 30 consecutive patients with unilateral severe carotid stenosis who underwent angioplasty and stent placement. Resting cerebral blood flow (CBF) and cerebral vasoreactivity (CVR) to acetazolamide challenge were quantitatively measured to evaluate cerebral hemodynamic reserve. Split-dose \(^{123}\)I iodoamphetamine single photon emission CT (SPECT) was performed before and 7 days after carotid angioplasty and stent placement. Technetium-99m hexamethylpropyleneamine oxime (HMPAO) SPECT was performed immediately after the procedure.

RESULTS: Three patients had cerebral hyperperfusion phenomenon immediately after angioplasty and stent placement, as shown by HMPAO SPECT: One developed status epilepticus 2 weeks after the procedure. Significant predictors of hyperperfusion included patient age, pretreatment CVR, and pretreatment asymmetry index (\([\text{ipsilateral resting CBF/contralateral resting CBF}] \times 100\)). Variables determined not to be significant risk factors included pretreatment CBF value, degree of carotid stenosis, and interval from the onset of ischemic symptoms.

CONCLUSION: Significant predictors of hyperperfusion phenomenon after carotid angioplasty and stent placement include patient age, pretreatment CVR, and pretreatment asymmetry index. Pretreatment CBF measurements, including those obtained by quantifying CVR and performing SPECT immediately after the procedure may aid in identifying patients at risk and in initiating careful monitoring and control of blood pressure to prevent hyperperfusion syndrome.

Percutaneous transluminal angioplasty and stent placement are considered less invasive than carotid endarterectomy (CEA) for treatment of carotid stenosis, and they may provide an alternative to CEA, especially in patients deemed to be at increased risk for endarterectomy. Data on the benefits, risks, and complications of carotid angioplasty and stent placement are accumulating (1–3); documented complications include cerebral embolism, vessel dissection, hemodynamic compromise, and cerebral hyperperfusion syndrome. Cerebral hyperperfusion syndrome has been increasingly reported as a complication of carotid angioplasty and stent placement (4–6). However, the incidence of cerebral hyperperfusion after endovascular revascularization procedures of the extracranial carotid artery remains unclear. Few studies have been conducted to evaluate the incidence of hyperperfusion syndrome after carotid angioplasty and stent placement, whereas cerebral hyperperfusion syndrome is a recognized complication of CEA, with a reported incidence of 0.3–1.2\% (7–9). Results of several studies indicate that the prevalence of hyperperfusion syndrome after carotid angioplasty and stent placement may be greater than that of hyperperfusion syndrome after CEA (10, 11). Because cerebral hyperperfusion syndrome is associated with substantial morbidity and mortality, factors predictive of cerebral hyperperfusion after carotid angioplasty and stent placement must be identified to prevent...
reperfusion injury. The aim of the present study was to determine significant predictors of hyperperfusion after carotid angioplasty and stent placement. To our knowledge, there have been no previous studies of the predicting factors of cerebral hyperperfusion after carotid angioplasty and stent placement.

Methods

Patient Population

Between January 2001 and September 2003, 42 consecutive patients underwent carotid angioplasty and stent placement at the University Hospital of Gifu, Japan. We retrospectively reviewed 30 consecutive patients with unilateral severe carotid stenosis who underwent angioplasty and stent placement. The remaining 12 patients, who had bilateral carotid lesions, were excluded. Twenty-seven of the 30 patients were male, and three patients underwent carotid angioplasty and stent placement.

Cerebral Blood Flow Studies

Split-Dose T2\textsuperscript{123}I-Iodoamphetamine Single Photon Emission CT.—Resting cerebral blood flow (CBF) and cerebral vasoreactivity (CVR) to acetazolamide (ACZ) challenge were quantitatively measured to evaluate cerebral hemodynamic reserve. For this, single photon emission CT (SPECT) was performed before and 7 days after carotid angioplasty and stent placement (12, 13). We used a rotating three-head gamma camera (Prism3000; Picker, Cleveland, OH). Data were acquired in a continuous rotating mode in a reciprocal direction at 20 seconds per revolution for 66 minutes from 96 directions in a 64 × 128 matrix, with a section thickness of 5 mm in the transverse, sagittal, and coronal planes. An irregular, mirror-shaped region of interest was placed in the whole MCA territory of the unaffected hemisphere at the level of the parietal lobe, including the infarct, and in the corresponding contralateral region. The asymmetry index (affected side counts per pixel/contralateral side counts per pixel) was calculated. Hyperperfusion after carotid angioplasty and stent placement was defined as a CBF increase of >100%, as compared with the normal side, immediately after the procedure.

Procedural Technique

Patients were pretreated with aspirin (100 mg/day), ticlopidine (200 mg/day), or both for at least 3 days before the procedure. Carotid angioplasty and stent placement were performed by means of transfemoral catheterization with the patient under local anesthesia. Predilation was performed with a controlled-compliant balloon dilation catheter. The balloon size was selected according to normal luminal diameter of each internal carotid artery immediately distal to the stenotic segment (diameter at full dilation was usually 5 or 6 mm). The balloon was inflated with 6–8 atm for 60 seconds. If a satisfactory increase in diameter was not achieved or if substantial wall dissection was observed after the balloon dilation, a self-expandable stent (Smart stent; Cordis Endovascular Systems, Miami, FL) was deployed. Poststenting dilation was omitted to prevent embolic complications. Distal protection was not used during the procedure. Intravenous heparin was administered during the procedure (100 μg/kg plus 1000 μg/h) and not reversed at completion. Intravenous Argatroban (Daiichi Pharmaceutical Co., Ltd., Nishinomiya, Japan) was continued for 24 hours after the procedure (60 mg/24 h). A systolic blood pressure of less than 130 mm Hg was maintained for 1 week after the procedure. Usually, the carotid sinus reflex lowered the patients’ blood pressure after carotid angioplasty and stent placement; occasionally, intravenous catecholamine was necessary to maintain blood pressure.

Definition of Hyperperfusion Phenomenon and Hyperperfusion Syndrome

Hyperperfusion phenomenon was used to designate increased CBF after carotid angioplasty and stent placement (CBF increase of >100% compared with the normal side). Hyperperfusion syndrome was used to designate the development of clinical symptoms as a result of rapidly increased CBF in excess of that required to meet metabolic demands.

Statistical Analysis

Statistical analysis was performed, with descriptive statistics presented as the mean ± SD. The Student t test was used for univariate analysis. The Fisher exact probability test was used for proportion analysis. P < .05 was considered to indicate significance. A commercially available software package was used (Statview 5.0 software; SAS Institute Inc, Cary, NC).

Results

Stents (Smart stent; Cordis Endovascular Systems) were deployed in 25 patients, whereas satisfactory
dilation of carotid stenoses was achieved by means of balloon angioplasty alone in five patients. All carotid stenoses were successfully dilated. Carotid angioplasty and stent placement reduced pretreatment stenoses of 70–99% (94.0 ± 7.0%) to residual stenoses of 0–40% (15.1% ± 17.7%), according to the NASCET criteria. All patients tolerated the procedures well. No patient had new ischemic symptoms, and postprocedural CT scans revealed no cerebral hemorrhage during the periprocedural period. However, an 83-year-old man developed status epilepticus 2 weeks after the procedure, and CT scans revealed cerebral edema in the ipsilateral cerebral hemisphere. His seizure was difficult to control, and he had left-sided weakness as a sequel (Figs 1 and 2).

Changes in CBF and CVR

Three patients had cerebral hyperperfusion phenomenon, as shown by HMPAO SPECT immediately after the procedure (hyperperfusion group). In these patients, their pretreatment asymmetry index of 50.7–98.7% (70.2% ± 25.2%) increased to a post-treatment index of 111.4–120.3% (116.0% ± 4.5%). The asymmetry index was not significantly different in the other 27 patients (nonhyperperfusion group) before (91% ± 14.1) and after (95.16% ± 8.04) treatment (Fig 3). Univariate analysis demonstrated significant differences between the hyperperfusion and nonhyperperfusion groups in terms of patient age (78.3 ± 4.16 vs 66.7 ± 7.82), pretreatment ipsilateral CVR (6.3% ± 5.7 vs 40.3% ± 20.1), and pretreatment asymmetry index (70.2% ± 25.2 vs 91% ± 14.1) (Fig 4). No significant difference was observed between the two groups in pretreatment resting CBF value (19.6 ± 2.7 vs 25.1 ± 5.8 mL/100 g/min), the pretreatment degree of carotid stenosis (99% ± 0 vs 93% ± 7.2), and the interval from the onset of ischemic symptoms (120 ± 30 vs 122 ± 22.6 days) (Table 1). Seven days after the procedure, CBF and CBV measurement demonstrated that the asymmetry index had decreased to 105.3% ± 4.1 in the hyperperfusion group, whereas the asymmetry index of the nonhyperperfusion group (95.2% ± 8.0) exhibited no significant change (Fig 3). On postoperative day 7, resting CBFs of the hyperperfusion and nonhyperperfusion groups were 35.9 ± 12.9 and 26.8 ± 5.9 mL/100 g/min.
respectively, and CVRs were 13.6% ± 0.2 and 52.2% ± 21.9%, respectively. In the Fisher exact probability test for proportion analysis, variables determined to be significant predictors of hyperperfusion phenomenon included patient age >75 years, pretreatment CVR <20, and pretreatment asymmetry index <75%; P values for these variables are shown in Table 2.

**Discussion**

*Cerebral Hyperperfusion after CEA*

Cerebral hyperperfusion syndrome after CEA is a well-described complication. After surgical revascularization that alleviates a high-grade symptomatic stenotic lesion, hyperperfusion syndrome may occur as a result of a sudden, rapid increase in CBF in...
have been conducted (4). Although the hyperperfusion syndrome after carotid angioplasty and stent placement has not been extensively studied, a small number of studies of hyperperfusion syndrome after cerebral angioplasty are now underway (1, 2). The incidence of cerebral hyperperfusion syndrome after angioplasty and stent placement is becoming an increasingly common treatment for high-grade symptomatic stenoses involving the extracranial and intracranial arteries. Data on the benefits, risks, and complications of this procedure are accumulating, and several prospective trials comparing the results of CEA with angioplasty and stent placement are now underway (1, 2). The incidence of hyperperfusion syndrome after cerebral angioplasty and stent placement has not been extensively studied. A small number of studies of hyperperfusion syndrome after carotid angioplasty and stent placement have been conducted (4–6). Meyers et al (10) reported that five (6.6%) of 76 patients with carotid stenoses (10 intracranial, 66 extracranial) developed hyperperfusion syndrome after angioplasty and stent placement. Morrish et al (11) observed a 3.8% incidence of cerebral hemorrhage after carotid stent placement. In these studies, the incidence of cerebral hyperperfusion syndrome was greater than that reported for CEA. In the present study, hyperperfusion syndrome developed in one patient (3.3%), and SPECT scans obtained immediately after the procedure demonstrated hyperperfusion phenomenon in three patients (10%). This trend may reflect patient selection: High-risk patients (e.g., those with high-grade stenosis, and older patients with medical complications) who are regarded as suboptimal candidates for CEA are commonly referred for angioplasty and stent placement, and endovascular treatment involves different anticoagulation protocols. Stimulation of carotid baroreceptors with a balloon or carotid stent may play an important role in the development of delayed hyperperfusion syndrome, as in the 83-year-old patient described earlier. Carotid baroreceptor stimulation induces transient, sometimes prolonged, bradycardia and hypotension; subsequent rebound arterial hypertension may induce cerebral hyperperfusion.

**Risk Factors for Cerebral Hyperperfusion**

Several variables have been identified as risk factors for the development of post-CEA intracerebral hemorrhage. These include severe (>90%) ipsilateral stenosis, impaired collateral blood flow secondary to advanced occlusive disease in other extracranial cerebral vessels or an incomplete circle of Willis, perioperative and postoperative hypertension, and use of antiplatelet agents or other anticoagulants (14). Some surgical reports suggest that patients with preoperative hemodynamic failure are at definite risk for hyperperfusion syndrome (15–17). In a study by Hosoda et al (18), CBF significantly increased on the first postoperative day in subjects with reduced preoperative CVR but not in those with normal preoperative CVR. This finding suggests that the basic mechanism responsible for hyperperfusion is massive vasodilatation due to loss of vasoconstriction from chronic cerebral ischemia distal to the high-grade carotid stenosis. However, there have been no reported findings regarding predictors of postprocedural hyperperfusion after angioplasty and stent placement, to our knowledge. In the present study, patient age, pre-treatment CVR, and pretreatment asymmetry index were significant predictors of hyperperfusion phenomenon after carotid angioplasty and stent placement. These results suggest that, in older patients, profound cerebral ischemia with impaired hemodynamic reserve is the highest-risk situation for cerebral hyperperfusion phenomenon after carotid angioplasty and stent placement. When this treatment is required for such patients, extreme postprocedural care must be taken.

Although pretreatment resting CBF, degree of carotid stenosis, and interval from the onset of ischemic symptoms were not significant risk factors, the num-

### TABLE 2: Univariate analysis of variables related to hyperperfusion phenomenon

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hyperperfusion Group (n = 3)</th>
<th>Nonhyperperfusion Group (n = 27)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &lt;75 y (yrs)</td>
<td>3</td>
<td>4</td>
<td>.0086</td>
</tr>
<tr>
<td>CVR -20%</td>
<td>3</td>
<td>4</td>
<td>.0086</td>
</tr>
<tr>
<td>Pretreatment asymmetry</td>
<td>2</td>
<td>2</td>
<td>.0594</td>
</tr>
</tbody>
</table>

excess of that required to meet metabolic demands. Transient cerebral hyperemia can lead to severe unilateral headache, face and eye pain, confusion, seizures (7), focal neurologic deficits, and intracerebral hemorrhages. Intracerebral hemorrhage reportedly occurs in 0.4–1.8% of patients after CEA and accounts for approximately one-fifth of all perioperative strokes (8, 9). The prognosis for these patients is poor, with mortality rates of 36–63%; survivors have substantial morbidity. Piepgras et al (8) reported a 11.6% incidence of hyperperfusion, defined as a CBF increase of >100% after CEA; intracerebral hemorrhage developed in 3.3% of subjects with hyperperfusion. Hyperperfusion syndrome is thought to be the result of failed normal cerebral autoregulation involved in CBF, secondary to longstanding decreased perfusion pressure. This failure results in the cerebral arterioles being maximally dilated over a long period, with subsequent loss of their ability to constrict when normal perfusion pressure is restored. Autoregulatory failure and cerebral hyperperfusion persist for some time after revascularization, but the conditions eventually normalize. The pathologic consequences of autoregulatory failure appear similar to those of normal perfusion pressure breakthrough, which occasionally occurs after resection of cerebral arteriovenous malformations. In both of these conditions, restoration of normal CBF to a chronically underperfused brain can result in edema, capillary breakthrough, and perivascular hemorrhages in association with fibrinoid necrosis of small arteries and macroscopic hemorrhages.

### Cerebral Hyperperfusion after Carotid Angioplasty and Stent Placement

Percutaneous transluminal angioplasty and stent placement is becoming an increasingly common treatment for high-grade symptomatic stenoses involving the extracranial and intracranial arteries. Data on the benefits, risks, and complications of this procedure are accumulating, and several prospective trials comparing the results of CEA with angioplasty and stent placement are now underway (1, 2). The incidence of hyperperfusion syndrome after cerebral angioplasty and stent placement has not been extensively studied. A small number of studies of hyperperfusion syndrome after carotid angioplasty and stent placement have been conducted (4–6). Meyers et al (10) reported that five (6.6%) of 76 patients with carotid stenoses (10 intracranial, 66 extracranial) developed hyperperfusion syndrome after angioplasty and stent placement. Morrish et al (11) observed a 3.8% incidence of cerebral hemorrhage after carotid stent placement. In these studies, the incidence of cerebral hyperperfusion syndrome was greater than that reported for CEA. In the present study, hyperperfusion syndrome developed in one patient (3.3%), and SPECT scans obtained immediately after the procedure demonstrated hyperperfusion phenomenon in three patients (10%). This trend may reflect patient selection: High-risk patients (e.g., those with high-grade stenosis, and older patients with medical complications) who are regarded as suboptimal candidates for CEA are commonly referred for angioplasty and stent placement, and endovascular treatment involves different anticoagulation protocols. Stimulation of carotid baroreceptors with a balloon or carotid stent may play an important role in the development of delayed hyperperfusion syndrome, as in the 83-year-old patient described earlier. Carotid baroreceptor stimulation induces transient, sometimes prolonged, bradycardia and hypotension; subsequent rebound arterial hypertension may induce cerebral hyperperfusion.

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Although pretreatment resting CBF, degree of carotid stenosis, and interval from the onset of ischemic symptoms were not significant risk factors, the num-
ber of patients with the hyperperfusion phenomenon and syndrome was too low to categorically state that these variables are not predictive of hyperperfusion phenomenon after carotid angioplasty and stent placement. In addition, factors predictive of hyperperfusion phenomenon may differ from those associated with the hyperperfusion syndrome. Results from past studies suggest that more recent ischemic symptoms may be associated with hyperperfusion syndrome.

**Conclusion**

In the present study, significant predictors of hyperperfusion phenomenon after carotid angioplasty and stent placement included patient age, pretreatment CVR, and pretreatment asymmetry index. Pretreatment CBF measures, including quantification of CVR and SPECT findings immediately after the procedure may aid in identifying at-risk patients and in initiating careful monitoring and control of blood pressure to prevent hyperperfusion syndrome.

**References**