Postoperative Dilatation of Superficial Temporal Artery Associated with Transient Neurologic Symptoms After Direct Bypass Surgery for Moyamoya Angiopathy

Daizo Ishii, Takahito Okazaki, Toshinori Matsushige, Katsuhiro Shinagawa, Nobuhiko Ichinose, Shigeyuki Sakamoto, Kaoru Kurisu

Objective: In moyamoya angiopathy, transient neurologic symptoms (TNS) are occasionally observed after superficial temporal artery (STA)—middle cerebral artery (MCA) direct bypass surgery. The purpose of this study was to investigate the correlation between TNS and postoperative magnetic resonance imaging as well as perform a perfusion study.

Methods: We reviewed 52 hemispheres in 33 consecutive patients with moyamoya angiopathy. TNS were defined as reversible neurologic dysfunction without any apparent intracranial infarction or hemorrhage. All patients underwent magnetic resonance imaging and single-photon emission computed tomography before and within 5 days after surgery. Maximum diameter of STA on time-of-flight magnetic resonance angiography and the dilatation ratio of STA were calculated. The presence of signal changes on fluid-attenuated inversion recovery images and regional cerebral blood flow were also evaluated.

Results: TNS were observed in 13 of 52 (25%) cases 1–16 days after surgery. The mean preoperative STA dilatation, postoperative STA dilatation, and dilatation ratio of STA were 1.33 mm ± 0.27, 1.67 mm ± 0.30, and 29.31% ± 28.13%. Postoperative intraparenchymal cortical hyperintensity lesions and high-intensity signals in the cortex sulci (ivy sign) were detected in 24 (46.2%) cases and 29 (55.8%) cases, respectively. Univariate analyses demonstrated no association between TNS and postoperative signal change on fluid-attenuated inversion recovery images as well as cerebral blood flow. Only >1.5-fold dilatation of STA was significantly correlated with TNS (P < 0.0001).

Conclusions: STA dilatation was correlated with TNS after direct bypass surgery for moyamoya angiopathy.

Introduction

Moyamoya angiopathy (MMA) is an uncommon cerebrovascular disorder characterized by progressive stenosis or occlusion of the terminal portion of the bilateral internal carotid arteries. Direct bypass surgery by superficial temporal artery (STA)—middle cerebral artery (MCA) anastomosis is an established procedure and is considered the treatment of choice for ischemic MMA. Furthermore, a recent study revealed that direct bypass surgery for adult patients harboring hemorrhagic MMA reduced the rebleeding rate and improved the patient’s prognosis. The advantage of direct bypass surgery was to obtain immediate flow improvement; however, some patients may develop transient neurologic symptoms (TNS) owing to marked changes in blood flow. Previous studies demonstrated that TNS were observed in 17%–61%, usually within 14 days after successful bypass surgery, with headache, motor and/or sensory disturbance, dysarthria or...
magnetic resonance angiography were included in the MRI within 16 days after the surgery. Postoperative neurologic cranial hemorrhage; 3) all symptoms were resolved completely associated with postoperative acute cerebral infarction or intracranial disturbance, dysarthria, or aphasia; 2) symptoms were not follows: 1) transient neurologic deficits before the surgery. Medical and surgical records were retrieved, and retrieved data were analyzed retrospectively. Patient demographics and characteristics are summarized in Table 1.

**MATERIALS AND METHODS**

**Patients**
All study protocols were approved by the ethics committee of Hiroshima University. The study population comprised 52 hemispheres in 33 consecutive patients with MMA who underwent STA-MCA direct bypass surgery between September 2011 and December 2016. All patients were diagnosed with MMA according to angiographic findings defined by the Japanese Research Committee on MMA. Of patients, 16 were adults or adolescents (≥15 years old), and 17 were children (<15 years old). No patients had neurologic deficits before the surgery. Medical and surgical records were retrieved, and retrieved data were analyzed retrospectively. Patient demographics and characteristics are summarized in Table 1.

**Surgical Procedure**
All surgical procedures were performed by the same experienced vascular neurosurgeon (T.O.). In all cases, a parietal branch of the STA was anastomosed to a suprasyllavian MCA branch (M4). Indirect bypass by encephaloduroromyosynangiosis was also performed in 19 hemispheres of 11 pediatric patients under the requirement that the brain was not relatively edematous during the surgery.

**Transient Neurologic Symptoms**
We reviewed all patient medical records, and TNS were defined as follows: 1) transient neurologic deficits such as motor weakness, sensory disturbance, dysarthria, or aphasia; 2) symptoms were not associated with postoperative acute cerebral infarction or intracranial hemorrhage; 3) all symptoms were resolved completely within 16 days after the surgery. Postoperative neurologic findings were evaluated at least 3 times per day. The duration of TNS was also reviewed.

**Radiologic Examinations**
All patients underwent computed tomography and MRI before and within 5 days of surgery. Fluid-attenuated inversion recovery (FLAIR) MRI, diffusion-weighted imaging, and time-of-flight magnetic resonance angiography were included in the MRI protocol. Postoperative intraparenchymal cortical hyperintensity lesion (CHL) in the treated hemisphere (Figure 1) and linear high signal intensity lesions along the cortical sulci or brain surface in the treated hemisphere (“ivy signs”) (Figure 2) were detected on FLAIR images. Both CHL and ivy signs were distinguished from acute infarction or hemorrhage by computed tomography and diffusion-weighted imaging. An increase in postoperative ivy signs was defined as de novo ivy sign. If TNS lasted >5 days, MRI was performed repeatedly to investigate the occurrence of cerebral infarction or hemorrhage.

**Dilatation Ratio of STA**
The maximum diameter of the STA was measured at the straight section of the parietal branch on magnetic resonance angiography. Images were analyzed by 2 experienced vascular neurosurgeons (S.S. and T.M.) who were blinded to the neurologic condition and outcome of each case in a consensus reading using an open-source medical image viewer (Horos; http://www.horosproject.org/). Maximum intensity projections were reconstructed in axial, coronal, and sagittal views to identify running courses of the major trunk of the STA. Along the running course of the STA, longitudinal and perpendicular maximum intensity projection views (slab thickness of 2.2 mm) were reconstructed, and the maximum diameter of the STA was measured (Figure 3). The dilatation ratio of STA (rSTA) was calculated with the following formula: \( r_{STA} = \frac{STA_{post} - STA_{pre}}{STA_{pre}} \times 100 \).

**Cerebral Blood Flow Measurement**
Single-photon emission computed tomography using iodine-123-N-isopropyl-p-iodoamphetamine was performed in all patients before and within 3 days after the surgery. All cerebral blood flow (CBF) images were transformed into the standard brain size and

### Table 1. Baseline Characteristics of Study Patients

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean ± SD (range)</td>
<td>20.4 ± 18.6 (3–51)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>6 (18.2%)</td>
</tr>
<tr>
<td>Female</td>
<td>27 (81.8%)</td>
</tr>
<tr>
<td>Treated hemispheres</td>
<td></td>
</tr>
<tr>
<td>Adults</td>
<td>23 (44.2%)</td>
</tr>
<tr>
<td>Children</td>
<td>29 (55.8%)</td>
</tr>
<tr>
<td>Operative side</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>27 (51.9%)</td>
</tr>
<tr>
<td>Right</td>
<td>25 (48.1%)</td>
</tr>
<tr>
<td>Clinical type</td>
<td></td>
</tr>
<tr>
<td>Ischemia</td>
<td>38 (73.1%)</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>4 (7.7%)</td>
</tr>
<tr>
<td>Others</td>
<td>10 (19.2%)</td>
</tr>
</tbody>
</table>

Values are presented as number (%) except for age.
shape by linear and nonlinear parameters with the system for anatomic standardization developed by Minoshima et al. The region of interest was selected in bilateral MCA territories on both axial levels of the basal ganglia (MCA 1), the centrum semiovale (MCA 2), and bilateral cerebellum using NEURO FLEXER software (Nihon MediPhysics Co., Ltd., Tokyo, Japan). Regional CBF was evaluated using semiquantitative parameters calculated from mean single-photon emission computed tomography counts of the MCA territories and cerebellum, respectively. The cerebral-to-cerebellar ratio (rCC) was defined as the ratio of resting single-photon emission computed tomography counts in regions of interest of the treated MCA territories to the ipsilateral...
cerebellum. Preoperative patient hemodynamics were evaluated by rCC. The increasing rCC was calculated as the ratio of postoperative to preoperative rCC.

**Statistical Analyses**

All statistical analyses were performed using JMP version 10.0 (SAS Institute Inc., Cary, North Carolina, USA). Values are presented as mean ± SD. Categorical variables were compared by the Fisher exact probability test. Continuous variables with normal distributions were analyzed by Student t test and variables with non-normal distributions were analyzed by Mann-Whitney U test. The incidence of TNS was calculated, and the correlation of age, sex, side of hemisphere, operative procedure, type of preoperative symptom, rSTA, CHL, de novo ivy sign, preoperative rCC, and increasing rCC with TNS was evaluated using univariate analyses. Significance was defined as a P value < 0.05.

**RESULTS**

Successful patency of the direct bypass, which was assessed by intraoperative indocyanine green angiography and postoperative magnetic resonance angiography, was obtained in all patients. No stenosis at the anastomosis was seen in any of the cases. No symptomatic hemorrhagic or ischemic complications were observed.

**Frequency and Variety of TNS**

TNS were observed in 13 (25%) cases 1–16 days after the surgery, lasting 7.3 days ± 4.0. Among all TNS, signs and symptoms observed included motor weakness in 5 (9.6%) cases, sensory disturbance in 8 (15.4%), dysarthria in 2 (3.8%), and aphasia in 7 (13.5%).

**Dilatation of STA**

No shrinkage of the anastomosed STA was observed after surgery. The mean maximum diameter of the preoperative and postoperative STA was 1.33 mm ± 0.27 and 1.67 mm ± 0.30, respectively. Based on these values, the mean rSTA was calculated as 29.31% ± 28.13. There was no significant correlation between indirect bypass procedure and rSTA (P = 0.92).

**Signal Changes on FLAIR Images**

No apparent CHL was found before surgery. Preoperative ivy sign was observed in 16 hemispheres in 10 (19.2%) patients. Postoperative CHL and de novo ivy sign in the treated hemisphere were detected in 24 (46.2%) and 29 (55.8%) cases, respectively.

**Postoperative CBF Increase**

The mean preoperative rCC at MCA 1 and 2 was 0.97 ± 0.17 and 0.95 ± 0.17, respectively. The mean increasing rCC at MCA 1 and
However, rSTA was significantly correlated with TNS. Preoperative rSTA as a continuous variable suggested that a 1% rise in rSTA would increase the risk of TNS by 7% (odds ratio 1.07, 95% confidence interval 1.04–1.12, P < 0.0001). Direct bypass surgery for MMA has been established; however, the relatively high incidence of TNS of 17%–61.0% is of concern. One study reported that patients with MMA have a significantly higher risk for symptomatic hyperperfusion as a potential complication of direct bypass surgery compared with other occlusive cerebrovascular diseases owing to the vulnerability to cerebral hyperperfusion in MMA.

The precise mechanism of TNS and its associated radiographic findings remain controversial. Studies have suggested vasogenic edema and local cortical hyperperfusion as causes of TNS, indicating some characteristic findings associated with these hypotheses. Moreover, transcranial Doppler ultrasound was reported to provide clinical data on the hemodynamics in MMA before and after revascularization. However, it was not evaluated in this study because of the necessity of sedation in most pediatric cases.

The appearance of a cortical hyperintensity belt (CHB) sign, which was defined as the presence of an intraparenchymal high-intensity signal on FLAIR images after direct bypass surgery for MMA, was demonstrated to be significantly correlated with TNS. It was speculated that the CHB sign was due to vasogenic edema, and it was hypothesized that preoperative vasodilatation and hemodynamic changes caused by direct revascularization may lead to autoregulatory failure and extravasation of fluid. In this study, CHL was defined in a similar manner with the CHB sign. Furthermore, all signs disappeared by 1 month after surgery, and no high signal intensity on diffusion-weighted imaging was observed, which was consistent with the signal trait of CHB signs. However, CHL was not significantly correlated with TNS. Thus, CHL itself may not be the cause of TNS, but rather may result from extravasation owing to autoregulatory failure, or the incidence of CHL may depend on the extent of vulnerability of the blood-brain barrier. The expression of vascular endothelial growth factor and matrix metalloproteinase 9, both of which affect the permeability barrier, was significantly increased in patients with MMA compared with healthy control subjects. Therefore, vasogenic edema may be observed frequently after direct bypass surgery for MMA. Consequently, CHL may be observed occasionally with or without TNS.

A de novo ivy sign indicated a focal increase in CBF in pial vessels in MMA and was suggested as an independent factor related to postoperative symptomatic hyperperfusion. In this study, preoperative rCC was not correlated with TNS. Recently, preoperative CBF and cerebrovascular reserve were found not to predict postoperative symptomatic hyperperfusion in MMA, which was consistent with our results. However, increasing rCC, which may be associated with hyperperfusion, and the de novo ivy sign were not correlated with TNS.

Regarding hemodynamics, studies have revealed that symptomatic hyperperfusion in MMA was characterized by temporary increases in CBF >100% over the preoperative value caused by prolonged recovery of increased cerebral blood volume (CBV). Preoperative CBV increase may be an independent predictor of both radiologic and symptomatic hyperperfusion after surgery in adult MMA. These reports suggested that TNS was, at least in part, correlated with increasing CBV before and after direct bypass surgery for MMA. Using intraoperative indocyanine green angiography, Awano et al. reported that the perfusion pressure in MMA was lower than in non-MMA, which may cause a larger pressure gradient between the anastomosed STA and recipient vessels. Theoretically, an increased CBV suggests autoregulatory

### Table 2. Factors Associated with Transient Neurologic Symptoms

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR</th>
<th>95% CI Lower</th>
<th>95% CI Upper</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.34</td>
<td>0.06</td>
<td>1.87</td>
<td>0.21</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>1.24</td>
<td>0.30</td>
<td>6.35</td>
<td>0.78</td>
</tr>
<tr>
<td>Side (left)</td>
<td>2.75</td>
<td>0.82</td>
<td>10.27</td>
<td>0.10</td>
</tr>
<tr>
<td>Operative procedure (indirect bypass)</td>
<td>0.37</td>
<td>0.09</td>
<td>1.30</td>
<td>0.12</td>
</tr>
<tr>
<td>Preoperative symptom (ischemial)</td>
<td>1.91</td>
<td>0.49</td>
<td>9.52</td>
<td>0.36</td>
</tr>
<tr>
<td>rSTA (&gt;50%)</td>
<td>28.33</td>
<td>5.80</td>
<td>218.74</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>CHL</td>
<td>2.62</td>
<td>0.79</td>
<td>9.27</td>
<td>0.11</td>
</tr>
<tr>
<td>De novo ivy sign</td>
<td>2.2</td>
<td>0.66</td>
<td>8.19</td>
<td>0.20</td>
</tr>
<tr>
<td>Preoperative rCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCA 1</td>
<td>3.08</td>
<td>0.18</td>
<td>63.48</td>
<td>0.44</td>
</tr>
<tr>
<td>MCA 2</td>
<td>2.31</td>
<td>0.16</td>
<td>39.24</td>
<td>0.54</td>
</tr>
<tr>
<td>Increasing rCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCA 1</td>
<td>0.42</td>
<td>0.02</td>
<td>10.87</td>
<td>0.59</td>
</tr>
<tr>
<td>MCA 2</td>
<td>0.65</td>
<td>0.03</td>
<td>15.93</td>
<td>0.78</td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio; rSTA, dilatation ratio of superficial temporal artery; CHL, cortical hyperintensity lesion; rCC, cerebral-to-cerebellar ratio; MCA, middle cerebral artery.

*Significant.
vasodilatation in response to the cerebral perfusion pressure reduction. It is speculated autoregulatory failure may occur in MMA; cortical arteries may be dilated, and cerebral perfusion pressure may be reduced before the surgery. Consequently, excessive increase in CBV may occur immediately after direct bypass surgery, which may induce TNS secondary to a metabolic disorder. Simultaneously, the marked dilatation of the STA may be induced with TNS as a result of a large pressure gradient between the graft and recipient vessel.

In the present study, the increasing rCC of MCA 1 and 2 was >1.0 (100%) in 20 (38.5%) and 24 (46.2%) cases, respectively. This suggested that “radiographic” hyperperfusion frequently occurs after direct bypass surgery for MMA; however, the incidence of “symptomatic” hyperperfusion may be relatively low. It has been reported that the CBF increased ratio with or without TNS was not significantly different between these 2 groups. Therefore, it seems controversial to attribute all causes of TNS to local hyperperfusion. Both CHL and local hyperperfusion are likely minimally related to TNS; however, rSTA may have a high sensitivity to TNS. Based on our results, we hypothesize that increasing CBV may be a primary cause of TNS, and rSTA may be a useful predictor of TNS after direct bypass surgery for MMA. If the diameter of the anastomosed STA increased >50%, blood pressure should be strictly controlled to avoid postoperative cerebral hemorrhage and/or epilepsy, and neurologic data should be evaluated frequently.

This study has some limitations. First, this was a retrospective cohort study in a single center with a small sample size. For further evaluation, a prospective study involving a greater number of patients and multivariate analysis may be needed for confirmation of these initial results. Second, CBF was evaluated using semiquantitative parameters. It was difficult to evaluate CBF quantitatively in children because of the necessity of arterial blood sampling. This lack of a highly quantitative evaluation regarding CBF may have contributed to the irrelevance between increasing rCC and TNS. Moreover, CBF was evaluated just 1 time within 3 days after surgery. Therefore, it is possible that CBF may further increase in the other acute phase after surgery. Third, an increase in CBV was not confirmed. CBV needs to be evaluated before and after surgery to validate our hypothesis described here.

CONCLUSIONS
In this retrospective study, rSTA was correlated with TNS after direct bypass surgery for MMA. The occurrence of TNS should be considered in patients whose anastomosed STA diameter increases >50%.

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