Prediction of the Clinical Outcome of Pediatric Moyamoya Disease With Postoperative Basal/Acetazolamide Stress Brain Perfusion SPECT After Revascularization Surgery

Young So, MD; Ho-Young Lee, MD; Seung-Ki Kim, MD; Jae Sung Lee, PhD; Kyu-Chang Wang, MD; Byung-Kyu Cho, MD; Eunjoo Kang, PhD; Dong Soo Lee, MD

Background and Purpose—We evaluated whether basal/acetazolamide stress brain perfusion SPECT performed after revascularization surgery can predict the further clinical outcome of patients with pediatric moyamoya disease.

Methods—A total of 77 (31 males, 46 females, age 6.6±3.2 years) patients with postoperative pediatric moyamoya disease who underwent basal/acetazolamide stress brain perfusion SPECT 6 to 12 months after revascularization surgery and who were followed-up >12 months after SPECT were included. Mean follow-up period after SPECT was 36±19 months. Sixty-two patients underwent bilateral encephaloduroarteriosynangiosis (EDAS), 14 bilateral EDAS, and 1 unilateral EDAS. Ordinal logistic regression analysis using 5 independent variables (infarction on preoperative MRI, age at the first operation, highest Suzuki stage on cerebral angiography, and regional cerebrovascular reserve on postoperative SPECT) against postoperative clinical outcomes was performed.

Results—Fifty-one patients had preserved reserve on postoperative SPECT and their clinical outcomes were excellent (30), good (15), fair (4), and poor (2); 26 patients had decreased reserve (excellent, 1; good, 7; fair, 14; poor, 4). On ordinal logistic regression analysis, age at the first operation (P=0.033) and reserve on postoperative SPECT (P<0.001) were statistically significant.

Conclusion—Basal/acetazolamide stress brain perfusion SPECT performed at 6 to 12 months after indirect bypass operation could predict the further clinical outcome of pediatric patients with moyamoya disease. Patients with decreased cerebrovascular reserve will have remaining neurological deficit and ischemic attacks on follow-up. (Stroke. 2005;36:1485-1489.)

Key Words: cerebral revascularization | moyamoya disease | outcome | tomography, emission, computed

Moyamoya disease is a progressive occlusive cerebrovascular disease of the internal carotid arteries or their branches with compensatory development of a fine collateral vascular network at the base of the brain (moyamoya vessels). For the diagnosis and evaluation of the moyamoya disease, cerebral angiography and MRI are usually performed. Basal/acetazolamide stress brain perfusion SPECT performed in pediatric moyamoya disease patients can disclose regions of decreased cerebral perfusion and cerebrovascular reserve, which can be improved by revascularization surgery, ie, indirect bypass operation.

Known prognostic factors for pediatric moyamoya disease after operation are preoperative multiple cerebral infarctions, early onset at a young age, perioperative complications such as ischemic events, high Suzuki stages on cerebral angiography, and surgical procedure itself. In our institute, basal/acetazolamide stress brain perfusion SPECT is performed for preoperative and postoperative evaluation of pediatric moyamoya disease patients. In this study, we evaluated whether basal/acetazolamide stress brain perfusion SPECT performed after the indirect bypass operation can predict the further clinical outcomes of pediatric moyamoya disease patients.

Materials and Methods

Patients

The indirect bypass operation for pediatric moyamoya disease patients started in 1987 at our institute. Most patients were treated with encephaloduroarteriosynangiosis (EDAS) until October 1995, and after that time most patients were treated with EDAS with bifrontal encephalogaleo(periosteal)synangiosis (ribbon EDAS). Basal/acetazolamide stress brain perfusion SPECT began in 1995. From 1987 to 2000, 201 pediatric moyamoya disease patients underwent indirect bypass operation, ie, EDAS or ribbon EDAS on involved cerebral hemispheres, with one side being followed by the other side. Among these 201 patients, 77 patients who satisfied the following criteria were enrolled in this study: (1) patients with bilateral (n=76) or unilateral (n=1) disease who underwent indirect bypass operation in the involved cerebral hemispheres; (2) patients in

Received February 18, 2005; final revision received April 10, 2005; accepted April 26, 2005.

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Stroke is available at http://www.strokeaha.org

DOI: 10.1161/01.STR.0000170709.95185.b1

1485
who underwent unilateral EDAS because of unilateral disease.

Male-to-female ratio was 31:46, and the age (mean ± SD) at the first operation was 6.6 ± 3.2 years (range, 7 months to 14 years). Forty-three patients had cerebral infarction on their preoperative MRI. Sixty-two patients underwent bilateral EDAS and 14 patients underwent bilateral ribbon EDAS without ribbon; one patient underwent unilateral EDAS because of unilateral disease. Suzuki stages of cerebral angiography of 153 involved cerebral hemispheres were as follows: stage 1, 8 hemispheres; stage 2, 32 hemispheres; stage 3, 72 hemispheres; stage 4, 36 hemispheres; stage 5, 5 hemispheres; stage 6, 0 hemispheres. The follow-up period after postoperative SPECT was 36 ± 19 months (mean ± SD; range, 12 to 90 months). Clinical characteristics of patients are summarized in Table 1.

### Basal/Acetazolamide Stress Brain Perfusion SPECT

Chloral hydrate syrup was used for the sedation of patients. For basal study, 9.25 MBq/kg of 99mTc-hexamethylpropyleneamine oxime (HMPAO; Amersham, Buckinghamshire, England) was intravenously injected and the acquisition started 5 minutes after. Ten minutes before the end of basal SPECT acquisition, 20 mg/kg of acetazolamide was injected intravenously. Five minutes after the end of basal study acquisition, 18.5 MBq/kg of 99mTc-HMPAO was injected, and the acquisition of stress study began 5 minutes after. Total procedure took ~45 minutes.5 Acetazolamide stress images were obtained by decay-corrected subtraction of basal images from the corresponding stress images.

A triple-head gamma camera (Prism 3000; Picker International) with a low-energy high-resolution fan beam collimator was used for acquisition. Forty step-and-shoot images per detector were acquired with intervals of 3° for 20 seconds per each step. The SPECT images were reconstructed with filtered back projection using a Metz filter on 128 × 128 matrix.13

Two nuclear physicians who were unaware of patients’ medical records performed visual interpretation of the SPECT images. Cerebellums were considered as the reference regions for visual inspection of basal and acetazolamide stress brain perfusion SPECT images. The SPECT images were assessed as either “preserved” or “decreased” regional cerebrovascular reserve (rCVR). Decreased rCVR was defined as cerebral perfusion of acetazolamide stress SPECT that fell into a lower color range from basal SPECT over at least one-third of any brain lobe.

### Assessment of Postoperative Clinical Outcomes

The postoperative clinical outcome of each patient was assigned to one of the following 4 categories on the last follow-up by their neurosurgeons: (1) excellent, the preoperative symptoms such as transient ischemic attacks have totally disappeared without fixed neurological deficits; (2) good, the symptoms have totally disappeared but the neurological deficits remained; (3) fair, the symptoms persisted but their frequency has decreased; and (4) poor, the symptoms remained unchanged or worsened.6,11

### Quantitative Analysis

To show the confidence of the visual finding, vascular reserve in the lesions was quantified and compared with the results of the visual analysis. Region of interest was drawn on the area with decreased perfusion and reference region (cerebellums). The count of lesion was normalized to the counts of interest was drawn on the area with decreased perfusion and reference

\[
CVRF = \frac{C_{acetazolamide} - C_{basal}}{C_{basal}} \times 100 \%
\]

where \(C_{acetazolamide}\) and \(C_{basal}\) are the normalized counts in acetazolamide and basal SPECT images, respectively.13

### Table 1. Clinical Characteristics of 77 Patients

<table>
<thead>
<tr>
<th>No. of Patients</th>
<th>Decreased rCVR (n=26)</th>
<th>Preserved rCVR (n=51)</th>
<th>Total (n=77)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD)</td>
<td>5.8 ± 3.0 y (7 mo to 14 y)</td>
<td>7.0 ± 3.3 y (1 to 14 y)</td>
<td>6.6 ± 3.2 y</td>
</tr>
<tr>
<td>Sex Male:Female</td>
<td>10:16</td>
<td>21:30</td>
<td>31:46</td>
</tr>
<tr>
<td>Highest Suzuki stages (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1 (4)</td>
<td>1 (2)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>II</td>
<td>1 (4)</td>
<td>12 (24)</td>
<td>13 (17)</td>
</tr>
<tr>
<td>III</td>
<td>12 (46)</td>
<td>25 (49)</td>
<td>37 (48)</td>
</tr>
<tr>
<td>IV</td>
<td>11 (42)</td>
<td>11 (22)</td>
<td>22 (29)</td>
</tr>
<tr>
<td>V</td>
<td>1 (4)</td>
<td>2 (4)</td>
<td>3 (4)</td>
</tr>
<tr>
<td>VI</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cerebral infarction on preoperative MRI (%)</td>
<td>17 (65)</td>
<td>26 (53)</td>
<td>43 (56)</td>
</tr>
<tr>
<td>Operative procedures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilateral EDAS (%)</td>
<td>4 (15)</td>
<td>11* (22)</td>
<td>15* (19)</td>
</tr>
<tr>
<td>Bilateral ribbon EDAS (%)</td>
<td>22 (85)</td>
<td>40 (78)</td>
<td>62 (81)</td>
</tr>
<tr>
<td>Follow-up angiography</td>
<td>n=33 hemispheres</td>
<td>n=68 hemispheres</td>
<td>n=101 hemispheres</td>
</tr>
<tr>
<td>Improved (%)</td>
<td>16 (49)</td>
<td>44 (65)</td>
<td>60 (59)</td>
</tr>
<tr>
<td>No change (%)</td>
<td>10 (30)</td>
<td>16 (24)</td>
<td>26 (26)</td>
</tr>
<tr>
<td>Aggravated (%)</td>
<td>7 (21)</td>
<td>8 (12)</td>
<td>15 (15)</td>
</tr>
</tbody>
</table>

EDAS indicates encephaloduroarteriosynangiosis; rCVR, regional cerebrovascular reserve on postoperative basal/acetazolamide stress brain perfusion SPECT; ribbon EDAS, EDAS with bifrontal encephalagaleo(periosteal)synangiosis.

*One patient underwent unilateral EDAS because of unilateral disease.
Analysis. The patients with decreased and preserved vascular reserve in visual analysis had significantly lower CVRI (P<0.05) than the patients who showed preservation of vascular reserve in visual analysis (~2.4±5.5%; P<0.001; Figures 2 and 3).

On ordinal logistic regression analysis, age at the first operation (P=0.033) and rCVR on postoperative SPECT (P<0.001) were statistically significant prognostic factors for further clinical outcome, whereas cerebral infarction on preoperative MRI (P=0.213), the highest Suzuki stage (P=0.479), and operative procedure (P=0.371) were not (Table 2).

On follow-up angiography, among 101 cerebral hemispheres studied, 60 showed improved, 26 showed no change, and 15 had aggravated Suzuki stages. There was no significant difference of the changes of Suzuki stages among 33 hemispheres with decreased rCVR and 68 hemispheres with preserved rCVR (P=0.26) (Table 1). There was also no significant difference of the changes of Suzuki stages among the patients with excellent, good, fair, and poor outcomes (P=0.62).

### Discussion

Pediatric moyamoya disease patients usually present with a transient motor weakness induced by hyperventilation. As patients blow on a toy or hot food, or cry, transient cerebral ischemia is caused by vasoconstriction secondary to a decreased arterial partial pressure of carbon dioxide. In addition to these transient problems, moyamoya disease patients have developmental delay in intelligence. Moyamoya disease is a unique cerebrovascular disease in that revascularization surgery can effectively prevent ischemic events and thus improve the long-term clinical outcome. Neurologic deficit and transient ischemic attacks are expected to be abolished, cognitive developments is expected to be normalized, and intelligence is expected to be improved after successful bypass surgery. This can happen because successful revascularization surgery is accompanied by catch-up growth and functioning of brain with normalized perfusion with ample perfusion reserve.

In this study, we found that pediatric patients with moyamoya disease who had decreased reserve still on postoperative basal/acetazolamide brain SPECT resulted in worse postoperative clinical outcomes. Though patients who underwent successful revascularization surgery on both cerebral hemispheres, decreased reserve on postoperative SPECT warrants close follow-up because these patients might need further intervention such as reoperation. Functional success accompanying successful anatomical revascularization could be diagnosed by cerebral perfusion and reserve on basal/acetazolamide brain SPECT in this study. Basal/acetazolamide brain perfusion SPECT performed at 6 to 12 months after the last revascularization surgery was chosen, because neovascularization in these hemispheres usually reaches a peak several months after the operation.

Various preoperative markers were reported to predict poorer postoperative outcome, but postoperative functional status of brain perfusion or reserve might influence further clinical outcome of these patients. In our analysis, as well as the early onset at a young age, decreased reserve on postoperative SPECT was a significantly poorer prognostic factor for further clinical outcome. However, the evidence of

### TABLE 2. Ordinal Logistic Regression Analyses for the Postoperative Clinical Outcomes of Patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infarction on preoperative MRI</td>
<td>0.213</td>
</tr>
<tr>
<td>Age at the first operation</td>
<td>0.033</td>
</tr>
<tr>
<td>Highest Suzuki stage</td>
<td>0.479</td>
</tr>
<tr>
<td>rCVR on postoperative SPECT</td>
<td>0.000</td>
</tr>
<tr>
<td>Operative procedure</td>
<td>0.371</td>
</tr>
</tbody>
</table>

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cerebral infarction on preoperative MRI, higher Suzuki grade on cerebral angiography, and operative procedure were not significant prognostic factors in our patient cohort. This is in contrast to our previous report that ribbon EDAS was more effective compared with simple EDAS in terms of clinical and functional outcome.6 This difference may be caused by the fact that among 77 patients only 15 patients underwent simple EDAS, whereas most of the patients underwent ribbon EDAS. Those who underwent simple EDAS underwent operation before the adoption of the basal/acetazolamide brain SPECT in our institution. Because patients with remaining neurological deficits without ischemic symptoms after operation were classified as having “good” clinical outcome, most of the patients with preserved rCVR who had cerebral infarction on preoperative MRI were classified as having “good” outcome group. This might be the reason why the evidence of cerebral infarction on preoperative MRI was not a significant prognostic factor in this study.

In pediatric patients with moyamoya disease, intellectual functions usually begin deteriorating after the onset of the first neurological symptoms.14 Revascularization surgery was found to prevent this deterioration of intellectual functions by improving the cerebral blood flow.16,17 A subgroup of 21 patients performed preoperative and postoperative intelli-
gence tests according to the Korean Educational Development Institute Wechsler Intelligence Scale for Children (KEDI-WISC). Of these 21 patients, the mean full-scale intelligence quotient of 15 patients with preserved rCVR on their postoperative SPECT increased after revascularization surgery, and that of 6 patients with decreased rCVR on postoperative SPECT decreased. Because the results of intelligence tests were consistent with their postoperative clinical outcome in these 21 patients, decreased rCVR on postoperative SPECT warrants further intervention such as reoperation.

We used quaternary outcome at the last follow-up. The follow-up period varied from 12 to 90 months. Though we believe that survival analysis with event-free period would have been possible, the neurological deficit was not a one-and-for-all event during follow-up, but instead intermittent with very mild to severe degrees. Subjects sometimes needed clinical attention. However, there still remains the possibility to subdivide the “decreased or preserved” rCVR into extent and areas involved. Semiquantitative or quantitative evaluation of decreased rCVR and the pursuit of the correlation with the frequency/severity of ischemic events would be interesting. In acetazolamide-challenged SPECT, HMPAO might not reveal the subtle compromise of perfusion reserve caused by poor linearity in highly perfused areas because the uptake of highly perfused cerebellums could be underestimated compared with the regions of interest. Therefore, normalized counts of the regions of interest in aceazolamide-challenged HMPAO images could have higher values than that in basal images, which might result in small positive values in some areas of preserved rCVR.

Follow-up angiography results of patients analyzed against rCVR of SPECT did not show statistically significant difference between patients with decreased rCVR and patients with preserved rCVR, nor did they between patients with different postoperative clinical outcomes. Because this study is focused on the role of postoperative SPECT of pediatric moyamoya patients, difference of time point among postoperative SPECT, postoperative clinical outcome, and follow-up angiography may be the reason for no significance. Postoperative clinical outcome was assessed 36±19 months after postoperative SPECT, which was performed 6 to 12 months after indirect bypass operation; follow-up angiography was performed 17±15 months after indirect bypass operation.

In this simplified investigation, because we found that postoperative compromise in perfusion reserve was a foreboding for future ischemic attacks, we suggest that another helpful intervention such as reoperation should be conceived in this group of postoperative patients based on the basal/acetazolamide stress brain perfusion SPECT.

Summary

Basal/acetazolamide brain perfusion SPECT performed at 6 to 12 months after the completion of indirect bypass operation of the involved cerebral hemispheres could predict the further clinical outcomes of pediatric patients with moyamoya disease patients.

Acknowledgments

This study was supported by Korea Institute of Science & Technology Evaluation and Planning (KISTEP) through its National Nuclear Technology Program and by a grant from Brain Research Center of the 21st Century Frontier Research Program funded by the Ministry of Science and Technology, the Republic of Korea.

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*Stroke.* 2005;36:1485-1489; originally published online June 9, 2005;
doi: 10.1161/01.STR.0000170709.95185.b1
*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

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