The frequency of postoperative stroke in moyamoya disease following combined revascularization: a single-university series and systematic review

Clinical article

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Object. Although combined direct and indirect anastomosis in patients with moyamoya disease immediately increases cerebral blood flow, the surgical procedure is more complex. Data pertinent to the postoperative complications associated with combined bypass are relatively scarce compared with those associated with indirect bypass. This study investigated the incidence and characteristics of postoperative stroke in combined bypass and compared them with those determined from a literature review to obtain data from a large population.

Methods. A total of 358 revascularization procedures in 236 patients were retrospectively assessed by reviewing clinical charts and radiological data. PubMed was searched for published studies on surgical treatment to determine the incidence of postoperative complications in a larger population.

Results. Seventeen instances of postoperative stroke were observed in 16 patients (4.7% per surgery, 95% CI 2.8%–7.5%). Postoperative stroke was more frequent (7.9% per surgery) in adults than in pediatric patients (1.7% per surgery, OR 4.07, 95% CI 1.12–14.7; p < 0.05). Acute progression of stenoocclusive changes were identified in the major cerebral arteries (anterior cerebral artery, n = 3; middle cerebral artery, n = 1; posterior cerebral artery, n = 2). The postoperative stroke rate was comparable with that (5.4%) determined from a literature search that included studies reporting more than 2000 direct/combined procedures. No differences in the stroke rates between the direct/combined and indirect procedures were found. In the literature review, direct/combined bypass was more often associated with excellent revascularization (angiographic opacification greater than two-thirds) than indirect bypass (p < 0.05).

Conclusions. This experience of 358 consecutive procedures is one of the largest series for which the postoperative stroke rate for direct/combined bypass performed with a unified strategy has been reported. A systematic review confirmed that the postoperative stroke rate for the direct/combined procedure was comparable to that for the indirect procedure.

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Key Words • moyamoya disease • revascularization • complication • cerebral infarction • intracranial hemorrhage • vascular disorders

Moyamoya disease (MMD) is a progressive stenoocclusive cerebrovascular disease characterized by collateral vascular networks that look like “a puff of smoke” (moyamoya vessels) at the base of the brain.35,58 Various revascularization procedures have been shown to improve cerebral hemodynamics and decrease the risk of ischemic attack; however, hemodynam-

Abbreviations used in this paper: ACA = anterior cerebral artery; ICH = intracerebral hemorrhage; MCA = middle cerebral artery; MMD = moyamoya disease; PCA = posterior cerebral artery; STA = superficial temporal artery; TIA = transient ischemic attack.
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tion with lower perioperative stroke rates. However, the number of published indirect bypass cases is far greater than those of direct/combined bypass. The number of reports on outcomes in direct/combined bypass appears to have increased recently, and we speculated that the publication bias toward the indirect procedure may show a gradual improvement. However, because a substantially greater number of patients have undergone indirect bypass worldwide, limited information is available regarding the outcomes and frequency of complications in direct/combined bypass. We determined the postoperative stroke rate in direct/combined bypass by reviewing the data from cases in our experience and those reported in the literature.

Methods

Study Population

We examined our experience with 341 consecutive patients with MMD treated at the Department of Neurosurgery of Hokkaido University Hospital from March 1980 to March 2012, and its affiliate hospital (Asahikawa Red Cross Hospital) from March 2000 to March 2012. The diagnosis of MMD was made on the basis of the guidelines established by the Research Committee on the Pathology and Treatment of Spontaneous Occlusion of the Circle of Willis, from the Ministry of Health and Welfare of Japan. Patients with quasi-MMD were excluded from the analysis. We retrospectively reviewed chart and radiological imaging data. Because the data relevant to postoperative complications—including those involving hematocrit, hemoglobin, blood pressure, and PaCO₂ during anesthesia—were not available in patients treated during the earlier period, the analysis was not performed on these variables.

Perioperative Management

The patients were diagnosed by conventional angiography and/or MRI and MR angiography (using a machine ≥ 1.5 T). Hemodynamic assessment was performed in every patient except those with severe neurological deficits by either [¹³¹]I-p-iodoamphetamine/SPECT or [¹⁵]O-gas PET. Cerebrovascular insufficiency was evaluated by either administration of 10 mg/kg acetazolamide on SPECT or measurement of the oxygen-extracting fraction on PET. Symptomatic hemispheres with decreased cerebrovascular reserve or elevated oxygen-extracting fraction were considered to be optimum candidates for the surgery. Between 1 and 3 days before the surgery, patients received 500–1000 ml/day of an intravenous drip for hydration. After induction of general anesthesia, PaCO₂ was strictly maintained above 35–40 mm Hg throughout the surgery. Postoperatively, both colloids and crystalloids (25% albumin and/or 6% hydroxyethyl starch) were administered for 3 consecutive days. In addition to volume supplementation, a fixed amount of fluid administration (1000 ml/day in pediatric patients, 1500 ml/day in adult patients) was continued throughout the 7 days after the surgery. Cerebral blood flow measurements were performed on Days 0, 2, and 7 to detect hyperperfusion on SPECT. When abnormal focal increases in cerebral blood flow were identified, defined as greater than 150% of the ipsilateral cerebellar hemisphere, administration of both colloids and crystalloids was discontinued. The systolic blood pressure was maintained within the range of 120–130 mm Hg. Antiplatelet therapy was used in 33.5% of pediatric patients and 16.2% of adult patients. The antiplatelet agent was discontinued 7 days prior to the surgery until 3 days after the surgery, a total of 10 days in the perioperative period.

Surgical Treatment

The surgical procedure was described in detail in previous investigations. Our surgical procedure is characterized by the universal application of direct bypass regardless of the patient’s age. The standard procedure consists of double superficial temporal artery (STA)–middle cerebral artery (MCA) anastomosis. After a large frontotemporal craniotomy, the dura is opened while preserving the middle meningeal artery. Both the parietal branch and the frontal branch of the STA are anastomosed to the cortical branch of the MCA. The dural flap is inverted and placed on the surface of the brain to increase collateral formation. The temporal muscle is sutured to the edge of the dura. In recent procedures, a paramedian craniotomy was also performed in selected patients to improve revascularization in the area of the anterior cerebral artery (ACA). The majority of these patients had received indirect bypass using the peristomal flap, whereas the remaining patients had received STA–ACA bypass. The temporal muscle was placed on the surface of the brain, completing encephaloduromyoarteriosynangiosis.

Definition of Postoperative Stroke

We use the term “postoperative stroke” to mean either infarction or intracerebral hemorrhage (ICH), intraventricular hemorrhage, and subarachnoid hemorrhage that developed during the surgery or within 4 weeks after the surgery. Hyperperfusion is a frequent complication observed mostly in adult MMD and can lead to ICH or seizure. However, the diagnosis of hyperperfusion largely depends on the definition and frequency of radiological studies. Furthermore, we have previously reported the frequency of hyperperfusion; therefore, we did not include hyperperfusion as postoperative stroke in this study. In addition, we did not include transient ischemic attack (TIA) in this study. Because previous temporary neurological deficits were considered to be ischemic symptoms, it was difficult to differentiate TIA from hyperperfusion in the retrospective analysis.

Systematic Review

Search Methods. We used “moyamoya,” “moyamoya disease,” “complication,” “revascularization,” and “surgery” as the keywords in a literature search of the PubMed database (last accessed February 1, 2013). The literature was independently reviewed by 2 authors (K.K. and M.I.) in accordance with the PRISMA statement for reporting systematic review. Any disagreement between
these authors was resolved in a consensus meeting with another author (K.H.).

Selection Criteria. We analyzed studies of patients who underwent vascular reconstruction surgery in MMD. Studies that analyzed and reported detailed data of postoperative stroke and outcome data were included. Studies that included less than 10 revascularization surgeries were excluded to decrease potential superselection bias.

Data Collection and Extraction. We extracted data on patient characteristics, surgical procedures, extent of revascularization, postoperative stroke, and long-term outcomes. Studies that did not report the outcome of surgical treatment and publications in languages other than English were excluded from the review. A standard data extraction sheet was used to abstract data from the original papers. We focused on the angiographic outcomes, which were classified as excellent (revascularization of more than two-thirds of the MCA territory), good (revascularization of one-third to two-thirds), and poor (revascularization of less than one-thirds) on the basis of previous literature. Postoperative stroke was investigated to compare complication rates between the direct/combined and indirect revascularization procedures.

Statistical Analysis. The Pearson chi-square test or Fisher exact test was used to analyze differences in dichotomous variables. The Student t-test or Wilcoxon rank-sum test was used to analyze differences in the mean or median of continuous variables between the groups. We calculated the mean values of postoperative stroke per surgery in each paper, then summarized them as mean estimated population proportions and 95% CIs. Variables (age, sex, clinical symptoms, and arterial involvement as assessed on MR angiography composite score20) that indicated a univariate relationship with postoperative stroke for p values < 0.1 without showing strong correlations with each other were considered for multivariate logistic regression modeling. The software program JMP Pro (version 10, SAS Institute) was used to perform all statistical analyses.

Results

Authors’ Series

Three hundred fifty-eight hemispheres in 236 patients underwent direct/combined bypass (bilateral, n = 120; unilateral, n = 79). Direct/combined surgery was performed in 181 hemispheres (90%) in 128 pediatric patients (< 18 years old) and in 77 hemispheres (92.7%) in 108 adults (≥ 18 years old; Table 1). Clinical presentation before the surgery was TIA in 115, infarction in 55, intracranial hemorrhage in 30, and others (such as asymptomatic, seizure, involuntary movement) in 36 patients. Postoperative stroke was observed in 17 instances in 16 patients (4.7% per surgery, 95% CI 2.8%–7.5%; 6.8% per patient, 95% CI 3.9%–10.8%). The average age in patients with postoperative stroke was 39.4 ± 19.5 years (range 6–69 years), which was significantly older than patients without postoperative stroke (mean 26.5 ± 19.3 years, range 1–71 years, p < 0.05). The logistic regression analysis revealed that the incidence of postoperative stroke was statistically different between the adult (7.91% per surgery) and pediatric patients (1.66% per surgery; OR 4.07, 95% CI 1.12–14.7; p < 0.05).

Postoperative hemorrhagic stroke was observed in 5 patients (Table 1). Postoperative hemorrhagic stroke was significantly more frequent in patients with a previous history of hemorrhage compared with other clinical symptoms (p < 0.05). Hemorrhage was identified at subcortical areas where we performed the direct anastomosis in 3 patients and in areas remote from the bypass in the remaining 2 patients (subarachnoid hemorrhage, n = 1; intraventricular hemorrhage, n = 1).

Cerebral infarction was observed in 12 patients (Table 1); 1 patient developed both intracranial hemorrhage and infarction in different locations. Preoperative clinical presentation of both TIA and cerebral infarction were not associated with postoperative infarction. Cortical infarctions were distributed in the ACA and/or MCA territories in 7 patients and in the posterior cerebral artery (PCA) territory in 4 patients. Infarctions were identified in the contralateral hemisphere to the operated side in 3 patients. In 6 patients, acute progression of stenoocclusive changes were identified in the major cerebral arteries (ACA, n = 3; MCA, n = 1; PCA, n = 2). One patient demonstrated perforator infarction in the anterior choroidal territory. None of the asymptomatic patients demonstrated postoperative stroke.

In 13 (81%) of 16 patients, severe hemodynamic impairment was preoperatively demonstrated either on SPECT (n = 5) or PET (n = 8). In 7 of 16 patients, the modified Rankin Scale scores became worse after stroke, whereas the remaining 9 patients recovered to their preoperative state.

Systematic Review

The study selection for the systematic review is summarized in Fig. 1. The PubMed search yielded 968 articles, of which 75 were considered to be relevant after filtering by title. After reviewing the abstracts, 15 studies were excluded because of duplication or from application of our selection criteria. After reviewing full-text versions, 35 studies that reported on a total of 3946 patients met the inclusion criteria (Fig. 1). The series includes 2 of our previous publications.35,37 These reports described retrospective cohort studies.

Of the 6203 hemispheres treated, 2032 were treated by direct/combined bypass (32.8%) and 4171 (67.2%) by...
indirect bypass. At institutions that mainly performed the direct/combined bypass, the procedure was completed in 50%–67.2% of the pediatric patients.6,15 Thirty-two studies (4161 patients) provided data on postoperative complications (Tables 2 and 3). The rates of postoperative stroke related to direct/combined and indirect revascularization were 5.4% (95% CI 3.4%–7.5%) and 5.5% (95% CI 3.7%–7.3%) per surgery, respectively (nonsignificant difference; Tables 2 and 3). Data regarding the ages of the patients with postoperative stroke were available for 2940 patients in 30 studies. Postoperative stroke related to direct/combined revascularization occurred in 2.7% of the pediatric patients and in 7.6% of the adult patients (p < 0.001). In the pediatric patients, perioperative stroke was significantly more frequent in indirect bypass (6.0%) compared with direct/combined bypass (2.5%; OR 2.36, 95% CI 1.48–3.76; p < 0.001). In adult patients, there were no significant differences in postoperative stroke between direct/combined bypass (7.6%) and indirect bypass (5.1%).

The angiographic results of revascularization were available in 10 studies of 1252 hemispheres (direct/combined, n = 254, 20.3%; indirect, n = 998, 79.7%; Table 4). Postoperative angiography showed excellent neovascularization (angiographic opacification in more than two-thirds MCA territory) in 146 (57.5%) of 254 direct/combined bypasses and 293 (29.4%) of 998 indirect procedures. Comparison of direct/combined bypass with indirect bypass showed that excellent revascularization was significantly more frequent in the direct/combined group (p < 0.05). Postoperative angiography showed poor neovascularization (angiographic opacification < one-third MCA territory) in 17 (6.7%) of 254 direct/combined bypasses and 192 (19.2%) of 998 indirect procedures. Comparison of indirect bypass with direct/combined bypass showed that poor revascularization was significantly more frequent in the indirect group (p < 0.01).

Data regarding recurrent stroke in long-term follow-up were available in 735 patients in the direct/combined bypass group (12 studies; average follow-up period 3.8 years, 95% CI 2.4–5.1 years) and 963 patients in the indirect bypass group (9 studies; average follow-up period 4.4 years, 95% CI 2.9–5.9 years). Recurrent stroke rate in direct/combined revascularization occurred in 3.5% (95% CI 1.0%–6.0%), and in 11.2% (95% CI 3.5%–18.9%) of the patients with indirect bypass (p < 0.05).

Information on the characteristics of postoperative stroke was available in 29 patients in 3 studies. Eighteen patients experienced ipsilateral infarction on the operated side, whereas 11 patients experienced contralateral infarctions. Hemorrhage was observed in 4 (3.8%) of 104 patients in 2 studies.

Discussion

In our practices, we have been using the direct/combined revascularization procedure universally except for patients with substantial brain damage. As a result, we believe that our experience of 358 consecutive procedures is one of the largest series for which the rate of postoperative stroke rate in direct/combined bypass per-
formed with a unified strategy has been reported.\textsuperscript{27,52} We also performed a systematic review to compare the rate of complications in our series with those of previous investigations and with those that used indirect procedures. The 4.7% postoperative stroke rate in the present study was comparable with the rate (5.4%) determined from a search of more than 2000 direct/combined procedures. A comparison showed that there were no differences in the stroke rate between the direct/combined and the indirect procedures in the search results. The number of published cases treated by the indirect procedure was approximately twice that of the cases treated by the direct/combined procedure. However, the trend toward increased use of the direct/combined procedure has been recently recognized.\textsuperscript{1,13} Both our series and the search results showed that postoperative stroke was more frequent in adult patients who underwent a direct/combined procedure. In addition, acute occlusive changes in major cerebral arteries were responsible for approximately half of all postoperative strokes.

Despite the fact that direct anastomosis is difficult to accomplish and requires time-consuming steps, the stroke rate in the direct/combined procedure was lower than that of the indirect procedure in the pediatric patients in the present study. We attribute this difference to the immediate increase of cerebral blood flow after surgery. The immediate increase in blood flow from direct bypass probably compensates for the detrimental effect that is frequently observed postoperatively, such as hypocapnia induced by crying, hypotension, and circulation volume loss. In contrast, the indirect procedure alone potentially decreases cerebral blood flow in the acute period after the surgery. The relatively small craniotomy used with the standard encephaloduroarteriosynangiosis procedure occasionally causes brain protrusion from the craniotomy site, particularly under management using hypocapnia during general anesthesia. Swelling of the temporal muscle may also aggravate increased intracranial pressure.\textsuperscript{10} As a result, patients with severe hemodynamic compromise potentially develop global ischemia postoperatively.\textsuperscript{56} Postoperative stroke primarily developed in the adult patients in the present study. The cause of ischemic stroke is partly attributed to progressive occlusion in the main cerebral arteries, as described in previous studies.\textsuperscript{21,38} Because the development of collateral vessels (moyamoya vessels) is generally not remarkable in adults, abrupt occlusion may cause more severe consequences in adults than in pediatric patients.\textsuperscript{17} Furthermore, hyperperfusion is more frequent in adults than in pediatric patients.\textsuperscript{60} Therefore, an immediate increase in cerebral blood flow may have a more detrimental effect on the operated hemisphere in adults than in pediatric patients. However, because revascularization using the indirect procedure

\begin{table}[h]
\centering
\begin{tabular}{|l|l|c|c|c|c|}
\hline
Authors & Year & No. of Operations & Patient Population & Ischemic Stroke (%) & Hemorrhagic Stroke \%
\hline
Karasawa et al., 1992 & JPN & 196 & pediatric & 2 (1.0) & 0  \\
Iwama et al., 1995 & JPN & 85 & adult & 4 (4.7) & 0  \\
Iwama et al., 1996 & JPN & 202 & pediatric & 11 (5.5) & 0  \\
Sakamoto et al., 1997 & JPN & 19 & pediatric & 0 & 0  \\
Suzuiki et al., 1997 & JPN & 46 & pediatric & 0 & 0  \\
Sakamoto et al., 1997 & JPN & 309 & pediatric & 7 (2.3) & 0  \\
Houkin et al., 1997 & JPN & 112 & both & 2 (1.8) & 2 (1.8)  \\
Okada et al., 1998 & JPN & 37 & adult & 0 & 2 (5.4)  \\
Khan et al., 2003 & CHE & 44 & both & 1 (2.3) & 1 (2.3)  \\
Mesiwala et al., 2008 & USA & 59 & both & 5 (8.5) & 7 (11.9)  \\
Guzman et al., 2009 & USA & 450 & both & 8 (1.8) & 16 (3.6)  \\
Kuroda et al., 2010 & JPN & 47 & pediatric & 2 (4.3) & 5 (6.6)  \\
Czabanka et al., 2011 & BRD & 23 & adult & 2 (8.7) & 2 (8.7)  \\
Jung et al., 2011 & ROK & 79 & adult & 9 (11.4) & 9 (11.4)  \\
Bang et al., 2012 & ROK & 61 & adult & 5 (8.2) & 8 (13.1)  \\
Fujimura et al., 2012 & JPN & 152 & both & 4 (2.6) & 8 (5.3)  \\
Gross et al., 2013 & USA & 35 & adult & 2 (5.7) & 2 (5.7)  \\
\hline
total & 2032 & 66 & 22 & 88  \\
\hline
mean estimated population proportion (95% CI) & & 4.1% (2.4%–5.9%) & 1.3% (0.29%–2.3%) & 5.4% (3.4%–7.5%)  \\
\hline
\end{tabular}
\caption{Summary of the literature search on direct/combined revascularization for MMD}
\end{table}
often results in insufficient revascularization in adults, the direct/combined procedure has been increasingly used. A limitation of this study was its retrospective nature. Because our surgical procedure also includes several steps of the indirect procedure (inverting dura matter, suturing temporalis muscle to the dura, and the placement of the pericranial flap), the result cannot be simply interpreted as a direct comparison between the direct STA-MCA bypass and indirect procedure alone. Detailed assessment of the perioperative systemic hemodynamics is crucial, including levels of PaCO2, hematocrit, circulating volume, and blood pressure, but it was beyond the scope of this study because these data were not available to enable such an analysis. In this study, a preceding ischemic attack increased the risk of postoperative stroke, which is consistent with a previous investigation. In addition, postoperative hemorrhage was predominantly observed in patients with a prior history of intracranial hemorrhage. A recent study revealed that propofol increased cerebral perfusion pressure during general anesthesia, which suggests that postoperative stroke may have been declining recently with improved anesthetic management. Hyperperfusion is a postoperative complication of clinical significance, however, a survey performed at our institution focusing on the issue has been previously published elsewhere. Furthermore, wound breakdown and/or infection was not assessed in the present study.

Although previous studies have mainly focused on PaCO2, circulating volume, hematocrit, and blood pressure as causes of perioperative stroke, postoperative infarction may also be associated with acute occlusive changes in the ACA, MCA, and PCA. This complication may result from the immediate increase in blood flow in the direct/combined bypass, which requires earlier detection to decrease the impact of neurological impairment. On the basis of the results, the complication rate in the direct/combined bypass procedure is considered an acceptable range for stroke prevention. In particular, pediatric patients may benefit more from the surgery, whereas the relatively high complication rate in adults requires additional attention during postoperative management.

Acknowledgments

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Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Kazumata, M Ito, Houkin. Acquisition of data: Kazumata, M Ito, Tokairin, Y Ito. Analysis and interpretation of data: Kazumata, M Ito. Drafting the article: Kazumata, M Ito. Critically revising the article: Kazumata, M Ito, Tokairin, Y Ito, Ishikawa, Kamiyama, Kuroda. Reviewed submitted version of manuscript: Kazumata, Tokairin, Y Ito, Houkin, Nakayama, Kuroda. Approved the final version of the manuscript on behalf of all authors: Kazumata. Statistical analysis: Kazumata. Study supervision: Kazumata, Houkin.

References

10. Fujimura M, Kaneta T, Shimizu H, Tominaga T: Cerebral is-

TABLE 4: Summary of reported angiographic outcomes after MMD surgery in the literature search

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Nation</th>
<th>No. of Operations</th>
<th>Patient Population</th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
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<tr>
<td>direct/combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kim et al., 2007</td>
<td>ROK</td>
<td>12</td>
<td>pediatric</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Kuroda et al., 2010</td>
<td>JPN</td>
<td>47</td>
<td>pediatric</td>
<td>43</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>76</td>
<td>adult</td>
<td>50</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Lee et al., 2012</td>
<td>ROK</td>
<td>61</td>
<td>adult</td>
<td>16</td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>Bang et al., 2012</td>
<td>ROK</td>
<td>58</td>
<td>adult</td>
<td>27</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>254</td>
<td></td>
<td>146</td>
<td>91</td>
<td>17</td>
</tr>
<tr>
<td>mean estimated population proportion (95% CI)</td>
<td>57.5% (13.3%–100%)</td>
<td>35.8% (12.5%–70.3%)</td>
<td>6.7% (0%–17.7%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>indirect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matsushima et al., 1997</td>
<td>JPN</td>
<td>16</td>
<td>pediatric</td>
<td>2</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Isono et al., 2002</td>
<td>JPN</td>
<td>19</td>
<td>pediatric</td>
<td>14</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Kim et al., 2007</td>
<td>ROK</td>
<td>24</td>
<td>pediatric</td>
<td>12</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Kim et al., 2010</td>
<td>ROK</td>
<td>526</td>
<td>pediatric</td>
<td>177</td>
<td>294</td>
<td>55</td>
</tr>
<tr>
<td>Dusick et al., 2011</td>
<td>USA</td>
<td>8</td>
<td>pediatric</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>adult</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Lee et al., 2012</td>
<td>ROK</td>
<td>77</td>
<td>both</td>
<td>8</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td>Bang et al., 2012</td>
<td>ROK</td>
<td>13</td>
<td>adult</td>
<td>0</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Bao et al., 2012</td>
<td>PRC</td>
<td>305</td>
<td>adult</td>
<td>70</td>
<td>162</td>
<td>73</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>998</td>
<td></td>
<td>293</td>
<td>513</td>
<td>192</td>
</tr>
<tr>
<td>mean estimated population proportion (95% CI)</td>
<td>37.9% (16.4%–59.4%)</td>
<td>38.0% (25.3%–50.8%)</td>
<td>24.1% (5.8%–42.4%)</td>
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</tbody>
</table>

* Revascularization was classified as excellent (> two-thirds of the MCA territory), good (one-third to two-thirds), and poor (< one-third) on the basis of previous literature. Excellent revascularization developed more frequently in the direct/combined group than in the indirect group (OR 2.87, 95% CI 2.18–3.78; p < 0.001). In contrast, poor revascularization was significantly more frequent in the indirect group than in the direct/combined group (OR 3.58, 95% CI 2.21–5.79; p < 0.01).
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45. Nomura S, Kashiwagi S, Utsuoka S, Uchida T, Kubota H, To


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