CEREBRAL REVASCULARIZATION FOR MOYAMOYA DISEASE IN ADULTS

Jayashree Srinivasan, MD, Gavin W. Britz, MD, and David W. Newell, MD

Moyamoya disease is a rare entity characterized by progressive occlusion of the arteries of the circle of Willis leading to ischemic events or hemorrhage (Fig. 1). The disease is most commonly found in Japan, where the incidence is estimated to be between one and three per million per year and where it has a bimodal age of presentation in the first decade of life and in the fourth decade of life.[7, 29] The disease has a significant female preponderance, with a ratio of approximately 40 women to 1 man in adults.[29] Although the disease is a well-recognized entity in Japan, it has been increasingly reported in the United States in patients of all ethnic descents. Cloft et al[5] reported on 18 US adults with moyamoya disease, 16 of whom were women. No significant risk factors were found, although four of the patients had evidence of fibromuscular dysplasia in the cervical internal carotid artery. In a series of 93 young US adults who presented with stroke, five were diagnosed with moyamoya disease, all of whom were women in the 24- to 40-year-old age group.[27] The role of inflammatory disease in the head and neck is not clear, nor is the contribution of genetic factors. In addition to primary moyamoya disease in which the cause of the arterial occlusion is unknown, secondary moyamoya disease may occur in the adult population. Conditions that may lead to moyamoya disease include arteriosclerotic disease, sickle cell disease, collagen vascular disease, and radiation therapy.[2] The angiographic findings in these latter patients are the same as those in patients with the primary disease.

PRESENTATION

Although children with moyamoya disease most commonly present with ischemic symptoms, this is not true for adults. Houkin et al[10] reported on 35 consecutive cases of adult moyamoya disease; they found a hemorrhagic presentation in 65% of cases and an ischemic presentation in 35% (see Fig. 1*C–F*). Similarly, Iwama et al[11] also studied 55 Japanese patients with adult moyamoya disease and found a hemorrhagic presentation in 60% of patients. In another report, however, Houkin[7] studied 48 adults and found a hemorrhagic presentation in only 38%. The most common hemorrhage is intraventricular in nature secondary to rupture of the fragile moyamoya vessels of the basal ganglia, thalamus, and ventricle. A few patients present with true subarachnoid

From the Department of Neurological Surgery, Northwestern University Medical School, Chicago, Illinois (JS); and Department of Neurological Surgery, University of Washington, Seattle, Washington (GWB, DWN)

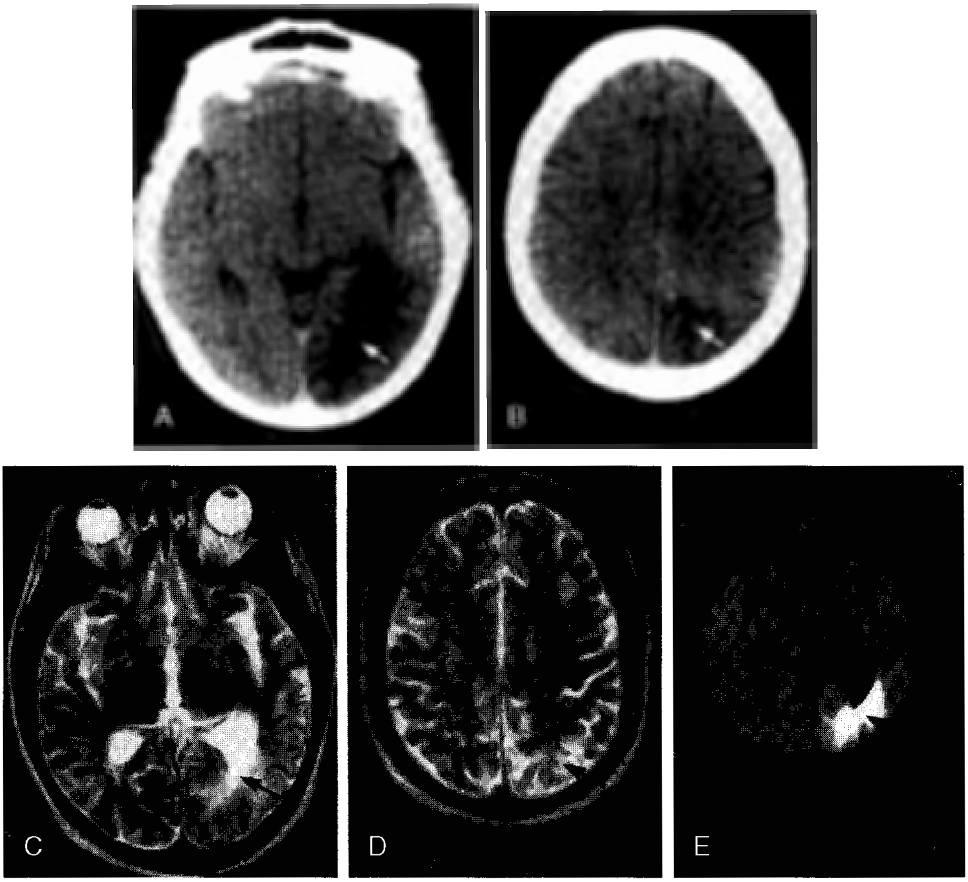

Figure 1. CT scan demonstrating an ischemic stroke (*arrows*) in the left posterior temporal, occipital, and parietal region in a young female patient who was later diagnosed with moyamoya disease (*A* and *B*). *C*, MR image with exacerbation of symptoms during preoperative evaluation that now demonstrates both the old stroke (*C* and *D*) and a new area of infarction demonstrated on the diffusion MR image (*E*).

Illustration continued on opposite page

hemorrhage, and the moyamoya disease is revealed on imaging studies. The pathophysiology of the hemorrhage in adults is thought to be related to two factors: long-term hemodynamic stress on the moyamoya vessels and arteriosclerotic vascular changes in adults.[7] In addition, it is postulated that hypoxic stress is a less important factor in adults than in children.[9]

In the few reported series of moyamoya disease in the United States, the presentation seems to be more frequently ischemic than hemorrhagic. Cloft et al[5] reported only three hemorrhages in 18 patients. The average age of these patients was 35 years. Chiu et al[3] described 26 adult patients who presented with moyamoya disease in Texas. Of these, 23 presented with ischemic events and three presented with hemorrhage. Based on these small series, it seems that moyamoya disease in non-Asian patients may manifest differently from the disease in the Japanese population.

There is an increased incidence of arterial anomalies in patients with moyamoya disease. The incidence of aneurysms in Japanese patients with moyamoya disease is approximately 5.6%.[31] The incidence of arteriovenous malformations associated with moyamoya disease has been reported to be as high as 3%.[17] In an analysis of 131 intracranial aneurysms in 111 patients with moyamoya disease, Kawaguchi et al[13] found that 56% of the aneurysms were detected on the circle of Willis. Of these 73 aneurysms, 43 (59%) were located in the posterior circulation; outside the circle of Willis, 24 aneurysms (18%) were located on small vessels in the basal ganglia and

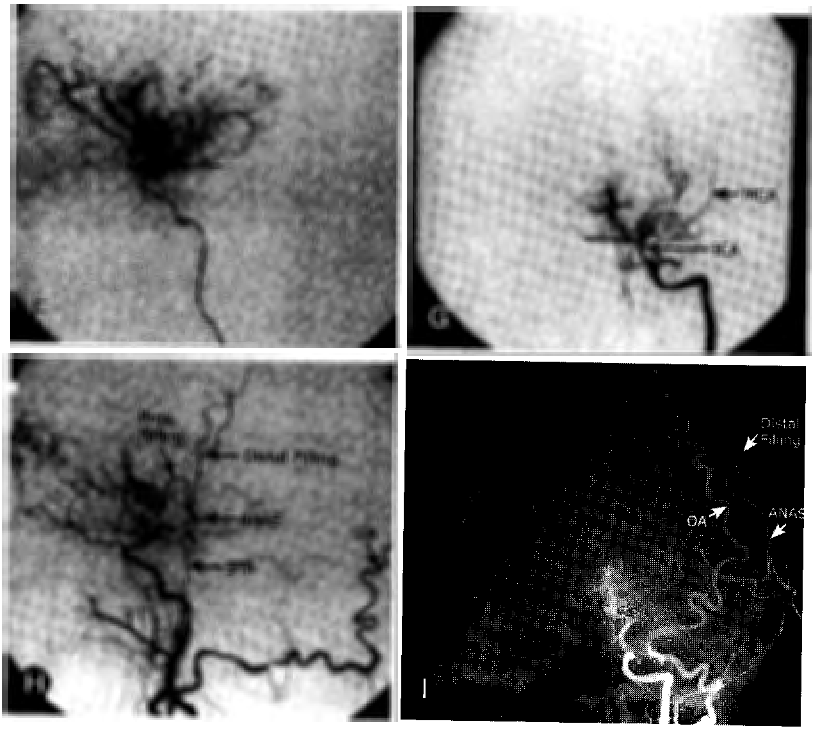

Figure 1 (*Continued*). Preoperative (and) and postoperative (and) angiograms. and are lateral views, and are anteroposterior views. The preoperative angiogram demonstrates supraclinoid carotid artery (ICA) occlusion with poor filling of the middle cerebral artery (MCA). The patient underwent an external carotid to internal carotid bypass. The postoperative angiogram demonstrates the successful anastomosis (ANAS) with good distal filling between the superficial temporal artery (STA) and a branch of the middle cerebral artery that has proximal filling (Prox. Filling). OA is the occipital branch of the external carotid artery.

29 (22%) were located on the choroidal arteries. The incidence of rupture of the aneurysms in the basal ganglia and choroidal vessels was greater than 90%, and these patients tended to present with a worse clinical grade than those with traditional subarachnoid hemorrhage.

NATURAL HISTORY

The prognosis of conservatively treated or untreated patients is poor regardless of the mode of presentation. A natural history study of only adults with ischemia has not been reported, and the data must be extrapolated from the pediatric literature. Olds et al[25] identified 39 pediatric patients in the literature who were followed for at least 2 years; 34 presented with transient ischemic attacks (TIAs), strokes, or seizures. Of these, only seven (21%) were normal at follow-up examination. Twelve (35%) remained unchanged, 10 (29%) declined neurologically, and five (15%) died.[25] Of their own eight patients with ischemia, who were treated conservatively and followed for a mean of 3.5 years, none was symptom-free and only one was neurologically intact at follow-up examination.[25] Choi et al[4] followed 52 pediatric and adult patients who were treated conservatively. In 67 months of follow-up of 35 patients with ischemia, the activities of daily living scores worsened in 49% and improved in only 26%. In contrast, in 36 patients treated with revascularization surgery in the same study, 55% improved and only 16% deteriorated. Even with TIAs alone, Kurokawa et al[16] noted that intellectual impairment developed in 62% of pediatric patients followed for at least 5 years.

In conservatively treated patients with hemorrhagic moyamoya disease, a rebleeding rate between 17% and 40% has been reported, with most series having several years of follow-up.[1] Nishimoto et al,[22] in the largest series of 175 patients with intracranial hemorrhage, found that 33% came to medical attention for rebleeding. The mortality for rebleeding was 30% in this series. When they studied the outcome of 271 patients with treated and untreated moyamoya disease, Nishimoto et al[22] noticed the worst outcome in patients who initially presented with hemorrhage: only 54% had a good outcome, whereas 77% of patients who presented with TIAs had a good outcome. The mortality for adults approaches 10%, which is twice the rate in the pediatric population.[29] More than two thirds of the deaths were secondary to intracranial hemorrhage.

DIAGNOSTIC STUDIES

Angiography

Cerebral angiography is the gold standard for the diagnosis of moyamoya disease. Suzuki and Takaku[28] have described the natural history of the disease in six stages. The earlier stages describe narrowing of the carotid arteries bilaterally, the middle stages describe the development of moyamoya vessels, and the later stages describe regression of the moyamoya vessels with development of extracranial to intracranial collateral pathways. The diagnostic guidelines for moyamoya disease posted by the Ministry of Health and Welfare in Japan include four criteria: (1) stenosis or occlusion of the intracranial internal carotid artery, adjacent anterior cerebral artery, or middle cerebral artery (MCA), (2) abnormal vascular network adjacent to the stenosed artery identified during the arterial phase of angiography, (3) bilateral findings on angiography, and (4) no other identifiable cause.[21]

Magnetic Resonance Imaging

Magnetic resonance (MR) imaging and MR angiography have recently been used to diagnose moyamoya disease. Houkin et al[8] studied 39 patients, 16 of whom were adults, who underwent conventional angiography and MR angiography. Although there was good correlation of steno-occlusive change in the carotid artery between MR angiography and conventional angiography, there was a tendency for MR angiography to overestimate the degree of disease. This was particularly true in the early stages of the disease. Overall, approximately 17% of cases were considered to be overestimated by MR angiography.[8] In adults, there was poor correlation between presence of moyamoya vessels on angiography and detection of these vessels by MR angiography: only 63% of moyamoya vessels were seen on MR angiography compared with conventional angiography.[8] The diagnosis of the disease may thus be erroneous in adults if MR angiography alone is used.

Computed Tomography

The use of CT in adult patients with moyamoya disease is primarily for the detection of acute hemorrhage and stroke (see Fig. 1). MR imaging better detects ischemic changes, and the moyamoya vascular changes are better detected by cerebral angiography.

Cerebral Blood Flow Studies

The role of cerebral blood flow (CBF) studies in adult moyamoya disease is not well characterized. Okada et al[24] used xenon-CT to calculate CBF in the MCA territory before and after superficial temporal artery-to-middle cerebral artery (STA-MCA) bypass. In their adult patients, those who presented with ischemia and those who presented with hemorrhage had a low preoperative CBF of 38 mL per 100 g/min. After surgery, both groups had an increase in CBF to 42 mL per 100 g/min, although it did not reach normal levels. Of importance, these investigators also measured cerebrovascular resistance and found it significantly elevated in the basal moyamoya vessels in both groups. Morimoto et al[20] studied CBF using positron emission tomography and found a low preoperative CBF in five adult patients, four of whom presented with hemorrhage. They also found an elevated oxygen extraction fraction in these patients. After STA-MCA anastomosis, there was an increase in regional CBF (rCBF), but, again, this value remained below normal limits. The oxygen extraction fraction decreased to 0.43, which was not statistically different from normal control values.[20]

Other groups have not detected abnormal resting CBF values preoperatively. Watanabe et al[30] used xenon single-photon emission CT to evaluate blood flow in six adult patients. They found that 84% of the regions of interest (ROIs) were within the normal range before encephalo-duro-arterio-myo-synangiosis (EDAMS). After revascularization, the number of ROIs with a normal rCBF increased to 95%. Watanabe et al[30] found that approximately 65% of patients had an abnormal response to acetazolamide before surgery, however. Although most of the diminished responses were located in the frontal and temporal regions, approximately 15% of the total ROIs had an abnormally high response to acetazolamide; these were primarily located in the parietal and occipital lobes. After surgery, 35% of ROIs retained a low response; however, most of the high-response regions normalized after surgery. Although these were only cortical measurements, Watanabe et al[30] did hypothesize that excessive dilatation in response to stress could be a potential mechanism for intracranial bleeding within the deep vessels of the basal ganglia and thalamus.

Kohno et al[15] studied 17 hemispheres of 12 adult patients treated with indirect revascularization. Overall, they found the resting CBF before surgery to be within the normal range at 50 mL per 100 g/min. The response to acetazolamide was significantly diminished compared with that in control patients, however. When CBF values were compared with extent of collateral formation on postoperative angiography, these investigators found that patients who had good collateral formation had the lowest levels of resting CBF before surgery and an extremely diminished response to acetazolamide.[15] After surgery, these patients had normalization of rCBF as well as an improvement in the response to Diamox (acetazolamide). Those who had poor collateral development had normal rCBF before surgery without a significant increase after surgery. Based on these findings, this group recommended indirect revascularization for patients with low CBF and poor vascular reactivity on preoperative testing.[15]

TREATMENT

The appropriate treatment for adult moyamoya disease remains controversial. In pediatric moyamoya disease, indirect revascularization using EDAMS has been found to induce excellent neovascularization.[9] This was thought to result from a greater degree of ischemia in pediatric patients as well as elevation of cytokines such as beta fibroblast growth factor (bFGF) in cerebrospinal fluid, both of which promote angiogenesis.[9] In adults, indirect revascularization procedures have been used with mixed success. Houkin et al[9] studied 22 hemispheres before and after surgery in adults. They found that direct STA-MCA anastomosis resulted in good revascularization of the MCA territory in 94% of cases. After indirect procedures, however, induction of neovascularization by the STA was observed in only 9% of cases, by the middle meningeal artery in 36% of cases, and by the deep temporal artery in 45% of cases. Mizoi et al[19] studied 16 adults who underwent direct and indirect bypass surgery and follow-up angiography an average of 6 months after surgery. In patients over 30 years of age, the direct bypass demonstrated excellent filling; however, in the same patients, the effectiveness of the indirect bypass declined with advancing age, particularly after the age of 40 years. These patients had all presented with ischemia, and during the follow-up period of 3.4 years, none of them had any further ischemic or hemorrhagic episodes.[19]

Kawaguchi et al[14] used multiple burr holes for the treatment of adult moyamoya disease. They operated on 10 patients who presented with only ischemic symptoms and determined the location of the burr holes by preoperative N-isopropyl-p[^{123}I] idoamphetamine (IMP) single photon emission CT. Angiography obtained an average of 6 months after surgery revealed evidence of good neovascularization in the region of most burr holes. Only six of the 18 treated sides demonstrated a decrease in the number of moyamoya vessels, however. Of these 10 patients, who were re-evaluated at an average follow-up interval of 35 months, all had improvement in their ischemic symptoms, and the two patients who had presented with intraventricular hemorrhage did not have any episodes of rebleeding. Interestingly, these investigators observed clinical improvement in their patients before they detected angiographic changes.[14] They concluded that patients with mildly decreased CBF at rest with a poor reactivity to acetazolamide were good candidates for burr hole revascularization.[14] Patients with large areas of infarcted tissue did not induce the same degree of neovascularization and could not be treated by this method.[14]

Although these small studies did reveal some benefit of indirect revascularization on the clinical outcome of adults with moyamoya disease, most of the literature favors direct arterial bypass for ischemic disease (Figs. 2 and 3).[9 12 18 20 23 24 30] The potential benefit of revascularization in hemorrhagic disease is thought to result from the reduction of hemodynamic stress on the basal moyamoya vessels. Its efficacy is difficult to assess from the literature. Although direct bypass does result in angiographic revascularization, reduction in moyamoya vessels is observed variably in 25% to 65% of adult patients and may be one reason for limited success in controlling hemorrhage.[10 24] Okada et al[24] described 30 patients, 15 of whom had presented with cerebral ischemic attacks. Of these 15 patients, 13 recovered and did not have any further ischemic or hemorrhagic events. The results for hemorrhagic disease have been less impressive. In the same group of patients who presented with hemorrhage, three of 15 had a rebleeding event after surgery.[24] Yonekawa et al,[32] reporting for the Ministry of Health and Welfare in Japan, used STA-MCA bypass surgery in 26 patients. Two of these patients (7.7%) suffered rebleeding during a follow-up period of 3.8 years. Although this rate of rebleeding seems to be somewhat less than that occurring during the natural history of the disease, it did not achieve statistical significance. Houkin et al[10] reported on 35 adult patients with moyamoya disease. Twenty-four of these patients presented with intracerebral hemorrhage, and 11 presented with cerebral ischemia. All 35 underwent direct bypass surgery and indirect revascularization. Over a mean follow-up

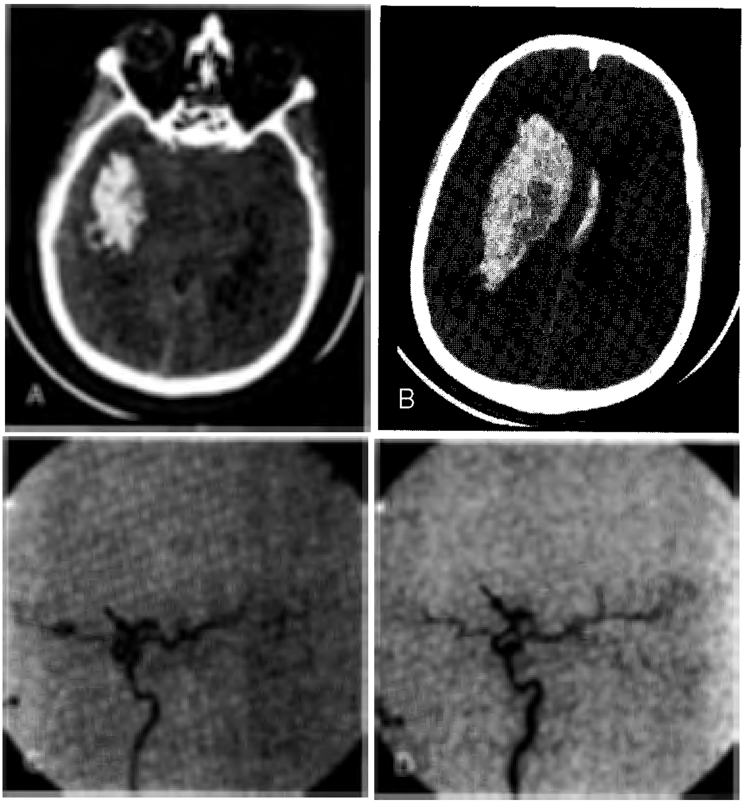

Figure 2. A 47-year-old man, previously in good health, presented with decreased level of consciousness. A CT scan (*A* and *B*) was performed that demonstrated an intracranial hemorrhage. An angiogram was performed to assess for a vascular etiology of the hemorrhage; this demonstrated bilateral supraclinoid carotid artery occlusion (*arrows*) consistent with moyamoya disease (*C* and *D*).

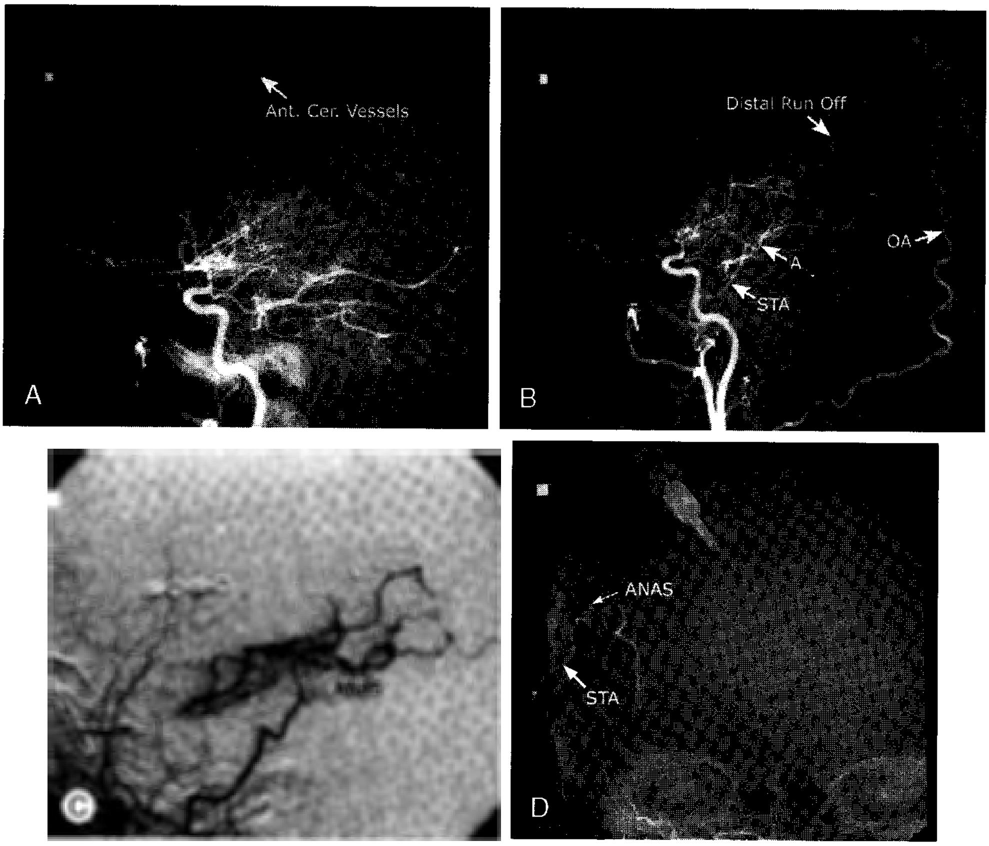

Figure 3. Preoperative ( ) and postoperative ( ) angiograms in a patient diagnosed with moyamoya disease. The preoperative angiogram demonstrates poor filling of the middle cerebral artery territory but filling of the anterior cerebral vessels (Ant. Cer. Vessels). The postoperative angiogram now demonstrates good distal run-off in the middle cerebral artery territory following a superficial temporal artery (STA) to a branch of the middle cerebral artery anastomosis (A). The occipital artery (OA) is well visualized. and , Close-up views of and

period of 6.4 years, five of the 35 patients (14.3%) had rehemorrhage. There were no postoperative ischemic events. These investigators concluded that although surgery was effective for prevention of ischemic attacks, its effectiveness against rebleeding was uncertain.[10] More recently, Kawaguchi et al[12] described 22 patients with hemorrhagic moyamoya disease. In this small series, 11 patients were treated conservatively, six underwent STA-MCA bypass, and five underwent EDAMS. During an average follow-up period of 7 years, 54% of the conservatively treated patients presented with rebleeding or an ischemic event, and three of the five (60%) patients treated with EDAMS also presented with a bleed or ischemic event. Of the six patients who underwent STA-MCA bypass, no patients had any neurologic difficulties after surgery. Interestingly, of those patients who underwent direct bypass surgery, revascularization was considered moderate in four and poor in two, indicating a discrepancy between clinical outcome and angiographic findings. In the treatment of hemorrhagic disease, it is thus not certain that revascularization of any form is completely effective in preventing rebleeding. It does seem that in ischemic and hemorrhagic moyamoya disease, STA-MCA bypass affords immediate revascularization of the area, whereas the indirect procedures take much longer to form collaterals and reduce symptoms.

In cases where patients present with a subarachnoid hemorrhage secondary to a ruptured saccular aneurysm, the conventional treatment of obliteration of the aneurysm by surgery or coiling is recommended. There are case reports of a distal aneurysm (e.g., choroidal) being treated by trapping of the parent artery. In general, this has been reserved for cases of recurrent intraventricular hemorrhage.[6]

TECHNIQUES OF REVASCULARIZATION

Indirect Bypass

For indirect revascularization, multiple elements may act as vascular donors. These include (1) the STA supplying the skin and galea aponeurotica, (2) the middle meningeal artery supplying the dura mater, and (3) the deep temporal artery supplying the temporal muscle. Usually, more than one of these donors is used to maximize the vascular potential.

The patient is positioned to allow access to the frontal, temporal, and parietal regions. In adults, the Mayfield headrest with three-point fixation is used. A Doppler probe is used to insonate the course of the STA and to identify the frontal and parietal branches. The scalp incision is made along the parietal branch of the artery extending from the root of the zygoma just anterior to the tragus superiorly and posteriorly, and it then curves anteriorly along the midline to the hairline. The authors have found the Colorado tip Bovie cautery extremely useful for incising the skin and subcutaneous tissues while preserving the STA. The STA is dissected along the incision distally to proximally until the bifurcation of the artery is reached. The superior portion of the scalp flap is then incised, and the scalp is retracted forward. Using the Bovie cautery, fine-tip bipolar cautery, and microscissors, the frontal branch of the STA is dissected and separated from the subcutaneous tissue of the scalp. The arteries are isolated with a small amount of connective tissue on either side of the artery. A frontotemporal craniotomy is then performed with careful attention paid to the middle meningeal artery. The bone flap is removed, and the dura is opened in a stellate fashion with preservation of the middle meningeal artery and its large branches. In indirect anastomosis, the STA is preserved in continuity with its distal end, and the two branches are laid over the surface of the brain. The dural flaps are inserted into the subdural space, and the dural defect is covered by temporalis muscle and pericranium. The bone flap is replaced carefully to prevent compression of the STA. Meticulous skin closure is required because of the risk of scalp necrosis in these patients.

Direct Revascularization

The technique for direct revascularization is similar to that for indirect revascularization. Once the dura has been opened, however, the two branches of the STA are dissected free from the surrounding connective tissue distally at a diameter appropriate for anastomosis to the MCA. Two temporary clips are placed on each branch of the STA, and one is placed on the main trunk proximally; the branches are then cut. Under the microscope, the adventitia is removed from the arterial end that is used for the anastomosis.

A temporal branch of the MCA on the surface of the brain is selected for anastomosis. The arachnoid overlying the artery is opened, and the artery is gently dissected free from the surrounding tissue. Because arteries tend to go into spasm with manipulation, a dilute papaverine solution may be used to vasodilate the artery. Excessive use of papaverine can damage the arterial wall; thus, limited use is recommended. The small perforating vessels off the MCA are coagulated with a fine-tip bipolar cautery and cut with microscissors. Once an appropriate length of vessel has been isolated, a small blue background is placed beneath the vessel to isolate the vessel from the surrounding brain. During the procedure, it is important to maintain normotension and normocapnia. After appropriate barbiturates are given, the vessel is cross-clamped with temporary aneurysm clips.

At this point, if only one branch of the STA has been isolated, an end-to-side anastomosis may be performed using 10-0 Ethilon suture in an interrupted fashion. If both branches of the STA are available, a double-barreled end-to-end anastomosis may be performed. Because this provides additional blood flow, this has been the preferred method. The end-to-end anastomosis may be performed in the standard fashion using interrupted 10-0 Ethilon suture or using the microanastomotic coupling device. Once the anastomosis is complete, the distal MCA clamp is released first to ensure there is no bleeding at the suture line; the STA clamp may then be removed. Once good hemostasis has been obtained, an indirect revascularization procedure may also be carried out as described previously using temporalis muscle and everting the dura beneath the bone.

The authors obtain a postoperative angiogram on their direct bypasses in the first few days after surgery to confirm that the bypass is patent. The angiogram may be repeated 3 to 6 months after revascularization to assess neovascularity and reduction of basal moyamoya vessels.

Anesthetic Risks

Oshima et al[26] reported on 17 patients who underwent revascularization. The authors monitored jugular bulb saturation intraoperatively and rCBF by laser Doppler flowmetry. They found that global hyperemia induced by either hypercapnia or isoflurane anesthesia could result in a fall in rCBF.[26] The poor response of the moyamoya vessels to hypercapnia and hypocapnia places the affected regions at significant risk for an intracerebral steal phenomenon. As a result, it is important during and after surgery to maintain pCO_2 at normocapnic levels and to maintain normotension. In addition, anesthetic agents such as propofol, which reduces CBF and metabolism, are preferred over agents such as isoflurane, which induces global hyperemia.

PERIOPERATIVE COMPLICATIONS

The incidence of perioperative complications in the literature has varied from 0% to 31%.[10, 29] Iwama et al[11] reviewed the perioperative hemodynamic complications in 55 adult patients. A total of 99 craniotomies were performed, and most of these patients underwent direct bypass surgery. Eight perioperative hemodynamic complications were noted, including two hemorrhagic infarctions. Intraoperative hypercapnia, hypocapnia, and hypotension were thought to be responsible for these ischemic events. The total incidence of complications was 14.5%, and this emphasizes the need for careful anesthesia in these patients.[11] Other potential complications include scalp necrosis secondary to the extensive subcutaneous dissection, subdural hematomas from temporal muscle hemorrhage, and postoperative seizures. The incidence of these complications is not known.

SUMMARY

The cause of and best treatment for adult moyamoya disease remain uncertain. These patients present either with ischemic or hemorrhagic symptoms, and without treatment, they have a high risk of future events. Direct STA-MCA bypass does seem to improve CBF and hemodynamics and also seems to reduce the risk of rebleeding, although it does not eliminate the risk. It is significantly more effective in prevention of ischemic episodes. Direct bypass does seem superior to indirect revascularization in adult patients, and a combined procedure may be performed when possible. Direct treatment of distal aneurysms is usually not indicated, because the aneurysms are often not visible on angiography. After revascularization, a decrease in the perfusion pressure in the basal moyamoya vessels is thought to reduce the hemodynamic stress that leads to vessel rupture. Because significant controversy surrounding the efficacy of therapy exists, a prospective controlled trial is necessary to truly determine the appropriate treatment.

ACKNOWLEDGMENT

The authors thank Ms Lisa Podewell for her assistance in preparation of the manuscript.

References

1. Aoki N: Cerebrovascular bypass surgery for the treatment of Moyamoya disease: Unsatisfactory outcome in the patients presenting with intracranial hemorrhage. Surg Neurol 40:372–377, 1993
2. Bitzer M, Topka H: Progressive cerebral occlusive disease after radiation therapy. Stroke 26:131–136, 1995
3. Chiu D, Shedden P, Bratina P, et al: Clinical features of moyamoya disease in the United States. Stroke 29:1347–1351, 1998
4. Choi JU, Kim DS, Kim EY, et al: Natural history of moyamoya disease: Comparison of activity of daily living in surgery and non-surgery groups. Clin Neurol Neurosurg 99(suppl):S11–18, 1997
5. Cloft HJ, Kallmes DF, Snider R, et al: Idiopathic supraclinoid and internal carotid bifurcation steno-occlusive disease in young American adults. Neuroradiology 41:772–776, 1999

6. Hamada J, Hashimoto N, Tsukahara T: Moyamoya disease with repeated intraventricular hemorrhage due to aneurysm rupture. Report of two cases. J Neurosurg 80:328–331, 1994
7. Houkin K: Cerebral revascularization surgery for moyamoya disease [Japanese]. No Shinkei Geka 27:211–222, 1999
8. Houkin K, Aoki T, Takahashi A, et al: Diagnosis of moyamoya disease with magnetic resonance angiography. Stroke 25:2159–2164, 1994
9. Houkin K, Kuroda S, Ishikawa T, et al: Neovascularization (angiogenesis) after revascularization in moyamoya disease. Which technique is most useful for moyamoya disease? Acta Neurochir (Wien) 142:269–276, 2000
10. Houkin K, Kamiyama H, Abe H, et al: Surgical therapy for adult moyamoya disease. Can surgical revascularization prevent the recurrence of intracerebral hemorrhage? Stroke 27:1342–1346, 1996
11. Iwama T, Hashimoto N, Tsukahara T, et al: Perioperative complications in adult moyamoya disease. Acta Neurochir (Wien) 132:26–31, 1995
12. Kawaguchi S, Okuno S, Sakaki T: Effect of direct arterial bypass on the prevention of future stroke in patients with the hemorrhagic variety of moyamoya disease. J Neurosurg 93:397–401, 2000
13. Kawaguchi S, Sakaki T, Morimoto T, et al: Characteristics of intracranial aneurysms associated with moyamoya disease. A review of 111 cases. Acta Neurochir (Wien) 138:1287–1294, 1996
14. Kawaguchi T, Fujita S, Hosoda K, et al: Multiple burr-hole operation for adult moyamoya disease. J Neurosurg 84:468–476, 1996
15. Kohno K, Oka Y, Kohno S, et al: Cerebral blood flow measurement as an indicator for an indirect revascularization procedure for adult patients with moyamoya disease. Neurosurgery 42:752–758, 1998
16. Kurokawa T, Tomita S, Ueda K, et al: Prognosis of occlusive disease of the circle of Willis ('moyamoya disease') in children. Pediatr Neurol 1:274–277, 1985
17. Mawad ME, Hilal SK, Michelson WJ, et al: Occlusive vascular disease associated with cerebral arteriovenous malformations. Radiology 153:401–408, 1984
18. Miyamoto S, Kikuchi H, Karasawa J, et al: Pitfalls in the surgical treatment of moyamoya disease. Operative techniques for refractory cases. J Neurosurg 68:537–543, 1988
19. Mizoi K, Kayama T, Yoshimoto T, et al: Indirect revascularization for moyamoya disease: Is there a beneficial effect for adult patients? Surg Neurol 45:541–549, 1996
20. Morimoto M, Iwama T, Hashimoto N, et al: Efficacy of direct revascularization in adult moyamoya disease: Haemodynamic evaluation by positron emission tomography. Acta Neurochir (Wien) 141:377–384, 1999
21. Nishimoto A: Moyamoya disease. Neurol Med Chir 19:221–228, 1979
22. Nishimoto A, Ueda K, Honma Y: Follow-up study on the outcome of the occlusion of the circle of Willis. *In* Gotoh S (ed): Proceedings of the Research Committee on Spontaneous Occlusion of the Circle of Willis. Tokyo, Ministry of Health and Welfare, 1982, pp 66–74
23. Nussbaum ES, Erickson DL: Extracranial-intracranial bypass for ischemic cerebrovascular disease refractory to maximal medical therapy. Neurosurgery 46:37–43, 2000
24. Okada Y, Shima T, Nishida M, et al: Effectiveness of superficial temporal artery-middle cerebral artery anastomosis in adult moyamoya disease: Cerebral hemodynamics and clinical course in ischemic and hemorrhagic varieties. Stroke 29:625–630, 1998
25. Olds M, Griebel RW, Hoffman HJ, et al: The surgical treatment of childhood moyamoya disease. J Neurosurg 66:675–680, 1987
26. Oshima H, Katayama Y, Hirayama T: Intracerebral steal phenomenon associated with global hyperemia in moyamoya disease during revascularization surgery. J Neurosurg 92:949–954, 2000
27. Smoker WRK, Biller J, Hingtgen WL, et al: Angiography of nonhemorrhagic cerebral infarction in young adults. Stroke 18:708–711, 1987
28. Suzuki J, Takaku A: Cerebral vascular "moyamoya" disease: A disease showing abnormal net-like vessels in the base of the brain. Arch Neurol 20:288–299, 1969
29. Ueki K, Meyer FB, Mellinger JF: Moyamoya disease: The disorder and surgical treatment. Mayo Clin Proc 69:749–757, 1994
30. Watanabe H, Ohta S, Oka Y, et al: Changes in cortical CBF and vascular response after vascular reconstruction in patients with adult onset moyamoya disease. Acta Neurochir (Wien) 138:1211–1217, 1996
31. Yabamuto M, Funahashi K, Fujii T, et al: Moyamoya disease associated with intracranial aneurysms. Surg Neurol 20:20–24, 1983
32. Yonekawa Y, Yamashita K, Taki W, et al: Clinical features of hemorrhagic type moyamoya disease: Special emphasis on cases with rebleeding. *In* Kikuchi H (ed): Annual Report (1988) of the Research Committee on the Spontaneous Occlusion of the Circle of Willis. Tokyo, Ministry of Health and Welfare, 1988, pp 81–88

Address reprint requests to

Jayashree Srinivasan, MD
Department of Neurological Surgery
Northwestern University Medical School
233 East Erie, Suite 614
Chicago, IL 60611