Cerebrovascular events (CVEs) consisting of ischemic strokes and transient ischemic attacks (TIAs) are among the most severe sequelae of sickle cell anemia (SCA). One in 10 children with SCA will experience stroke before the age of 20 years, and of these, up to 40% will have “moyamoya-like” collateral vessels on imaging. Although moyamoya disease (MMD) is idiopathic by definition, several conditions, including SCA, have been associated with similar clinical and radiographic features, known as moyamoya syndrome (MMS). The mechanism by which SCA causes MMS is not known, but arterial injury due to sickle cell occlusion of vasa vasorum and the response of the carotid arteries has been suggested.

Findings of MMS in patients with SCA confer a 5-fold greater risk of stroke than in the already high-risk group of patients who have SCA without MMS; therefore, the early diagnosis and treatment of MMS is of great importance. It has been shown that transcranial Doppler (TCD) screening can reduce the stroke rate 10-fold when transfusion protocols are instituted for elevated TCD velocities. However, medical management including transfusion protocols that are considered to be optimized for preventing other nonneurological sequelae of SCA are frequently inadequate to prevent CVEs in patients with SCA, especially...
those with MMS. Smaller single-center series at our institution and others have suggested that pial synangiosis may be a safe and effective treatment for prevention of secondary stroke in children with SCA and MMS. This report provides a review of the largest single-center experience of pial synangiosis in the management of MMS in children with SCA, as well as a comprehensive analysis of all reported cases in the literature.

Methods

We first conducted a retrospective review of patients presenting to Columbia University Medical Center/Morgan Stanley Children’s Hospital of New York (M SCHONY) with the dual diagnoses of MMS and SCA. All study procedures were conducted with institutional review board approval in accordance with state and federal guidelines; the Columbia University Medical Center Institutional Review Board approved all procedures in this study, which consisted of retrospective review of patient documentation. Patients undergoing pial synangiosis between 1996 and 2012 were included in the study. Children underwent pial synangiosis if they were symptomatic or had evidence of brain ischemia on MRI studies. Patients undergoing bilateral pial synangiosis had staged operations typically 4–6 weeks apart to allow for recovery. Patient demographic information, medical history, SCA therapies, and presenting symptoms were assessed. Follow-up records from the hematology, neurology, and neurosurgery departments were used to assess for postoperative progression or stability of neurological symptoms. Preoperative and follow-up angiography and MR angiography were assessed for vessel occlusion, graft patency, neovascularization, and flow in the affected distal cerebral arteries. A Student t-test was used to compare individual preoperative to postoperative stroke rates in the MSCHONY cohort.

For the comprehensive review, we performed a literature search to identify all reported pediatric patients with SCA who had a pial synangiosis procedure for MMD. We combined all patients and performed similar analyses to the degree possible based on the available literature.

The pial synangiosis procedure has been described previously by our group and others, but a few elements specific to children with SCA deserve emphasis. Perioperative hematology and anesthesia management is key. Preoperatively, due to the complex hemodynamic and hematological state of patients with SCA who experience concomitant cerebrovascular insufficiency due to MMS, we prefer to admit them the day before surgery to optimize hydration using intravenous fluids, and if necessary, transfuse to a hemoglobin level greater than 10 g/dl and hemoglobin sickle cell genotype (HbSS) less than 30%. Intraoperatively, anesthetic management focuses on minimization of cerebral metabolic rate of oxygen consumption and maintenance of cerebral blood flow. Frequent arterial blood gas assessments are made to prevent hypocarbia. We maintain normothermia to avoid the risk of sickle cell crisis associated with hypothermia and the increased cerebral metabolic rate associated with hyperthermia. Postoperatively, adequate pain control is essential to prevent crying and the concomitant hyperventilation, hypocarbia, cerebral vasoconstriction, hypoperfusion, and increased metabolic demand. Intraoperative monitoring is helpful to assess cerebral blood flow during the surgical procedure. Baseline somatosensory evoked potentials and electroencephalography studies are obtained just prior to the induction of anesthesia and continued until the end of the operative procedure. If changes are seen, anesthetic parameters can be rapidly initiated to restore optimal cerebral blood flow.

From a surgical perspective, the basic procedure is nearly identical to that for patients without SCA. It consists of a craniotomy with dural and pial openings through which, typically, a large branch of the superficial temporal artery (STA) with a vascular cuff is sutured to the pial surface. The proximal and distal ends of the STA remain intact extracranially and the vessel remains patent throughout the procedure. The craniotomy flap is replaced so that there is an inferiorly placed proximal bur hole through which the proximal STA enters the skull, and there is a superiorly placed distal bur hole through which the distal STA exits the skull.

Despite the basic similarity, there are still some nuances of the procedure specifically in the SCA population that may be useful to the neurosurgeon already well versed in the procedure in patients without SCA. Due to the hematopoietic demands of their hemolytic anemia, patients with SCA commonly have substantially thickened skulls compared with other patients with MMS. Therefore, we typically create a groove for the transposed vessel to sit in by drilling out the inner table and cancellous bone of the craniotomy flap, thereby preventing kinking or stretching of the donor artery. Also, in our experience, the donor vessel can often be more tortuous and ectatic than in patients without SCA, with more and smaller branches, making the dissection and preservation of the vessel more difficult.

Results

Groups Included

Pial synangiosis for MMS in a child with SCA was first described by Vernet et al. in 1996 (Table 1). This case report described an 8-year-old girl with bilateral strokes who underwent a bilateral STA pial synangiosis, and had another stroke at the age of 9 years despite good radiographically confirmed ingrowth of vasculature as a result of her first surgery. She then underwent bilateral occipital artery (OA) pial synangioses for progression of disease, largely in the posterior circulation.

Smith and colleagues recently reported a series of 12 patients, all of whom had suffered a stroke, a TIA, or both a stroke and TIA preoperatively; there was a low rate of perioperative complications, no neurological events (stroke, TIA, hemorrhage, seizure) during the follow-up period, and good radiographic results (Table 1).

The MSCHONY cohort is the largest to date (27 procedures in 17 patients), with the longest mean follow-up duration of 57 months (Tables 2 and 3). As demonstrated by Table 1, it is remarkably similar to the experience of Smith et al. in nearly all facets. One novel aspect of this...
Surgical management of moyamoya and sickle cell disease

In our group there were no perioperative neurological complications, but there were 3 minor nonneurological complications (11% of procedures; see Table 3). Two patients required antibiotics for superficial wound infections, and 1 patient developed a pseudomeningocele that resolved without operative intervention and was treated with steroids. Regarding neurological events in the follow-up period, 1 patient underwent a right-sided pial synangiosis procedure and suffered an episode of left-sided face and upper-extremity weakness 3 weeks later. An MRI study demonstrated a small right-sided infarct. These symptoms resolved with rehabilitation, and the patient remained in good neurological condition at last follow-up 78 months postoperatively. Another patient suffered a TIA affecting the left lower extremity 18 months after right-sided pial synangiosis. Her MR angiography studies demonstrated good collateral vasculature in the right hemisphere. She is free of further neurological events 113 months postoperatively. The third patient developed psychotic features 29 months postoperatively, but has been subsequently delusion-free with medical management through the last follow-up visit 75 months postoperatively.

Combined Results

When all 3 patient groups were combined, a total of 48 pial synangiosis procedures were performed in 30 patients (Table 1). Eighteen (60%) underwent surgery on both hemispheres. The median age at operation was 12 years, and the group consisted of 14 boys and 16 girls. Twenty-three patients (77%) were African American and 7 (23%) patients were Hispanic. Twenty-three patients (77%) had suffered an ischemic stroke prior to surgery, and 13 (43%) had suffered an ischemic stroke while on chronic transfusion therapy. Seventeen (57%) had experienced TIAs, 8 (27%) had had at least 1 seizure, and no patients had documented cerebral hemorrhage. Three patients (10%) were diagnosed during screening with TCD ultrasonography.

Clinical Outcome

In the combined data, chronic transfusion exchange was continued in all patients on an exchange regimen, except in 1 patient in the Smith group in whom it was successfully discontinued. The mean length of follow-up was 53 months, for a total of 1590 patient-months. There have been 4 postoperative neurological events (2 strokes, 1 TIA, and 1 new onset of psychosis), for a rate of 1 neurological event per 398 patient-months, or 1 per 33 patient-years. When individual strokes per patient-years were calculated from the MSCHONY data for the pre- and postoperative periods, there was a more than 6-fold reduction in the stroke rate after surgery; from 1 stroke per 13 patient-years to 1 stroke per 81 patient-years (p = 0.0003).
Radiographic Outcome

On preoperative vascular imaging, all of the combined patients manifested involvement of anterior circulation vessels (Fig. 1). Both clinically recognized strokes reported in the follow-up period were confirmed with imaging studies (one on CT, one on MRI studies). Long-term vascular screening images (MR angiography or catheter angiography) at a mean of 25 months postoperatively were available in 39 treated hemispheres (81%), and in 34 of those hemispheres (87%), imaging demonstrated

**TABLE 2: Presenting patient information from the MSCHONY cohort***

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs) at 1st Op</th>
<th>Sex</th>
<th>Race</th>
<th>Presenting Sx</th>
<th>Past Strokes</th>
<th>Past TIAs</th>
<th>Past Szs</th>
<th>Occlusion</th>
<th>Complete</th>
<th>Partial</th>
<th>Bilat Disease</th>
<th>Transfusion Regimen</th>
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<tbody>
<tr>
<td>1</td>
<td>13.6</td>
<td>M</td>
<td>H</td>
<td>Sz</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>rt ICA, lt M1</td>
<td>lt A1</td>
<td>yes</td>
<td>episodic</td>
<td>episodic</td>
</tr>
<tr>
<td>2</td>
<td>12.7</td>
<td>M</td>
<td>AA</td>
<td>stroke</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>rt ICA, lt MCA</td>
<td>lt ICA</td>
<td>yes</td>
<td>episodic</td>
<td>episodic</td>
</tr>
<tr>
<td>3</td>
<td>10.7</td>
<td>F</td>
<td>AA</td>
<td>stroke</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>rt ICA, lt MCA, rt ACA, lt M1, lt A1</td>
<td>yes</td>
<td>episodic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>17.7</td>
<td>F</td>
<td>H</td>
<td>stroke</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>lt ICA</td>
<td>lt A1</td>
<td>no</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
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<td>M</td>
<td>AA</td>
<td>Sz</td>
<td>2</td>
<td>0</td>
<td>1</td>
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<td>chronic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>7.8</td>
<td>M</td>
<td>H</td>
<td>Sz</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>bilat A1</td>
<td>lt ICA</td>
<td>yes</td>
<td>chronic</td>
<td>chronic</td>
</tr>
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<td>7</td>
<td>7.0</td>
<td>F</td>
<td>AA</td>
<td>TIA</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>lt ICA, rt A1/A2</td>
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<td>F</td>
<td>AA</td>
<td>TIA</td>
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<td>0</td>
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<td>F</td>
<td>AA</td>
<td>screening</td>
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<td>0</td>
<td>0</td>
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<td>chronic</td>
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<td>F</td>
<td>AA</td>
<td>stroke</td>
<td>2</td>
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<td>1</td>
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<td>11.3</td>
<td>F</td>
<td>H</td>
<td>stroke</td>
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<td>1</td>
<td>0</td>
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<td>yes</td>
<td>chronic</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>6.8</td>
<td>F</td>
<td>H</td>
<td>stroke</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>rt ICA</td>
<td>no</td>
<td>chronic</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>12.2</td>
<td>M</td>
<td>AA</td>
<td>TIA</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>rt M1/A1</td>
<td>yes</td>
<td>chronic</td>
<td></td>
<td></td>
</tr>
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<td>9.8</td>
<td>M</td>
<td>AA</td>
<td>TIA</td>
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<td>0</td>
<td>1</td>
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<td>17.5</td>
<td>M</td>
<td>H</td>
<td>stroke</td>
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<td>0</td>
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<td>lt ICA</td>
<td>no</td>
<td>chronic</td>
<td>chronic</td>
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<td>AA</td>
<td>screening</td>
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<td>chronic</td>
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<td></td>
</tr>
<tr>
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<td>14.2</td>
<td>F</td>
<td>AA</td>
<td>screening</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>bilat ICA</td>
<td>yes</td>
<td>chronic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* BA = basilar artery; H = Hispanic; Sx = symptoms.

**TABLE 3: Surgeries and outcomes in the MSCHONY cohort***

<table>
<thead>
<tr>
<th>Case No.</th>
<th>No. of Ops</th>
<th>1st Side</th>
<th>Latest FU Imaging (mos)</th>
<th>Graft Patent</th>
<th>Collat</th>
<th>Periop Complication</th>
<th>New Postop Neuro Event</th>
<th>Neuro Outcome</th>
<th>FU (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>lt</td>
<td>43</td>
<td>yes</td>
<td>yes</td>
<td>cont intermittent Szs</td>
<td>82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>rt</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>stable</td>
<td>115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>lt</td>
<td>15</td>
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<td>yes</td>
<td>stable</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>lt</td>
<td>24</td>
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<td>yes</td>
<td>stable</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>rt</td>
<td>13</td>
<td>yes</td>
<td>yes</td>
<td>WI</td>
<td>death (PE)</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>lt</td>
<td>3</td>
<td>yes</td>
<td>yes</td>
<td>WI</td>
<td>ischemic stroke</td>
<td>stable</td>
<td>78</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>lt</td>
<td>26</td>
<td>yes</td>
<td>yes</td>
<td>PM</td>
<td>stable</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>rt</td>
<td>45</td>
<td>yes</td>
<td>1 side only</td>
<td>stable</td>
<td>75</td>
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<tr>
<td>9</td>
<td>1</td>
<td>rt</td>
<td>23</td>
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<td>yes</td>
<td>psychosis</td>
<td>controlled psychosis</td>
<td>77</td>
<td></td>
</tr>
<tr>
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<td>1</td>
<td>rt</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>stable</td>
<td>48</td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>lt</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>stable</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>rt</td>
<td>15</td>
<td>yes</td>
<td>yes</td>
<td>TIA</td>
<td>stable</td>
<td>113</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>rt</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>stable</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2</td>
<td>rt</td>
<td>8</td>
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<td>no</td>
<td>stable</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>2</td>
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</tr>
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<td>16</td>
<td>1</td>
<td>rt</td>
<td>10</td>
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<td>stable</td>
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</tr>
<tr>
<td>17</td>
<td>1</td>
<td>lt</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>stable</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Cont = continued; NA = not available; PE = pulmonary embolism; PM = pseudomeningocele; WI = wound infection.
significant collateral vessels (Fig. 2). In the MSCHONY cohort, all imaged hemispheres demonstrated a patent graft. In one patient in the MSCHONY cohort an additional anterior bur hole was placed, and this patient had a good radiographic result involving both sites (Fig. 3). Interestingly, no patient with unilateral disease at presentation was found to develop contralateral disease following pial synangiosis during the follow-up period in any study.

Discussion

In this comprehensive review we have shown that 1) pial synangiosis is technically successful in these patients and promotes radiographically visible collateralization in more than 80% of operations; and 2) patients undergoing pial synangiosis have a very low rate of further neurological sequelae on long-term follow-up.

Clinical Presentation of MMS in Patients With SCA

Moyamoya syndrome can present clinically with a variety of manifestations, including ischemic stroke, hemorrhagic stroke, and seizure; ischemic stroke is the most common presentation in children. All of the cohorts studied are consistent in finding that ischemic events (ischemic stroke and TIA) occurred in 26 (96%) of the 27 patients who presented due to symptoms rather than for screening. Hemorrhage was absent in all patients studied, again consistent with reports of MMD in the pediatric population. The pathophysiological relationship between SCA and MMS is uncertain. It has been hypothesized that the hypercoagulable state of reduced red cell deformability may cause stenosis of the vasa vasorum of large
FIG. 4. Flowchart of recommended protocol for MMS screening in asymptomatic patients with SCA.
vessels, leading to vessel wall ischemia and hyperplasia of intimal cells. Subsequently, altered flow patterns from hyperviscosity of the blood may contribute to the occlusion of the major vessels, proliferation of MMS collateral vessels, and subsequent ischemic episodes.22

Medical Treatment of MMS in Patients With SCA

The primary goal of treatment for patients with SCA who have MMS, as in all patients with SCA, is to minimize the risk of a variety of potentially life-threatening vasooclusive events, including stroke and acute chest syndrome. Medical treatments such as chronic transfusion therapy have been shown to be effective in lowering the risk of stroke in patients with SCA by up to 90%, but these treatments are not without significant side effects,18,19,26,34,35 and their effectiveness in treating MMS in these patients is not clear. Chronic transfusion therapy has suboptimal results when used for patients with SCA who have already developed MMS as seen on radiographic imaging. A single-center study6 of 44 pediatric patients found that, despite receiving transfusion therapy to keep levels of HbSS below 30%, at a mean follow-up of 6.6 years, patients with SCA and MMS had a significantly greater risk of experiencing at least 1 recurrent CVE compared with patients with SCA who did not have MMS (57.9% vs 28%; p < 0.05). Patients with MMS were also found to have a significantly greater risk of experiencing 2 recurrent CVEs (42.1% vs 8%; p < 0.05).

This evidence suggests that patients with SCA who have MMS may not respond to medical therapy that is considered adequate for other patients with SCA, and is consistent with the preoperative findings in our surgical cohort. This suggests that the high rate of failure of medical therapy is not simply a factor of selection bias. A total of 17 known strokes were reported over 215 patient-years of life prior to surgery. In contrast, a single stroke was reported over 80 patient-years of postoperative follow-up. This represents a 6-fold greater risk of stroke prior to pial synangiosis (p = 0.0003). However, chronic transfusion therapy may still reduce the risk of progression of MMS, particularly in unilateral disease; none of the patients with unilateral disease in any study have developed contralateral MMS in the follow-up period.19 This may, however, also reflect differences in the pathophysiological mechanisms of MMS in patients with SCA compared with patients who have idiopathic MMD, in which contralateral progression frequently occurs within 2 years of diagnosis of unilateral disease.15

Neurosurgical Treatment of MMS in Patients With SCA

Pial synangiosis is the most common operation in the management of pediatric MMD and SCA. This review supports the finding that pial synangiosis has a relatively low risk of complications, significantly reduces the rate of CVEs, and maintains preoperative neurological status.24,37 Concerns have been expressed in the past that SCA would predispose patients to graft occlusion, but the data presented here16,18,29 have consistently shown graft patency and the development of new collateral vessels in patients with SCA who were treated with pial synangiosis. Variations to this procedure when appropriate have been associated with encouraging outcomes, namely those using combinations of pial synangiosis with bur holes and pial synangiosis with other indirect revascularization procedures.20

The pial synangiosis procedure has several advantages in the pediatric population with SCA over other surgical interventions for MMS, primarily direct STA–middle cerebral artery (MCA) bypass, bur holes alone, or encephalomyosynangiosis. Whereas some evidence24,25 suggests a significant decrease in cerebral ischemia following direct bypass, other evidence shows that pediatric STA-MCA revascularization is associated with significant complications including symptomatic hyperperfusion,10,12 acceleration of ipsilateral stenosis,17 and perioperative ischemic injury due to temporary arterial occlusion. Given the high morbidity and mortality rates8,24,40 in this procedure and the small arterial diameters of the STA and MCA in children, the STA-MCA bypass is less commonly performed in the treatment of MMS in pediatric patients.

In contrast to STA-MCA bypass, pial synangiosis is less time-consuming, less technically challenging, and associated with lower perioperative complications due to patency of the STA throughout the entire procedure. Pial synangiosis by its nature will not induce hyperperfusion because direct anastomosis is never established during the procedure. Neovascularization in pial synangiosis has been observed to develop over a larger portion of the brain than with direct revascularization procedures.36 In addition, the smaller vessel size and higher susceptibility to angiogenesis in children make pial synangiosis a preferred procedure in pediatric populations.21

Compared with bur holes alone, the length and physical proximity of artery to brain provided by pial synangiosis probably improves the rate and extent of neovascularization. Pial synangiosis similarly has several advantages over encephalomyosynangiosis, including a smaller incision, a smaller craniotomy, and more rapid revascularization on angiographic imaging.13 However, these methods may be more useful in particular patient groups, including patients who lack an STA robust enough to undergo pial synangiosis.

There is some debate with regard to the appropriate method of bilateral pial synangiosis. It is our preference to perform surgery in each hemisphere as a separate procedure due to concerns about the increased risk of complications in lengthy procedures with hemodynamically challenging patients such as these. The period between surgeries allows for neurological and hematological recovery and stabilization prior to the second procedure. In contrast, some other authors prefer a single anesthesia procedure despite the increased length of surgery.31 None of the 10 patients in our cohort who underwent bilateral pial synangiosis developed new-onset CVEs or neurological deficits in the interoperative period. Furthermore, there were no perioperative complications in either cohort that could potentially be attributed specifically to undergoing 2 procedures. It is not reported if any of the bilateral operations in the cohort of Smith et al31 were followed by perioperative complications, but the overall low rate of complications (15%) suggests that decisions
on which technique to use should be primarily based on surgeon and patient preference.

Only a small proportion of MMS occurs in patients with SCA. Despite the higher stroke risk in patients with SCA compared with other MMS patients, as well as their anesthetic and vascular anatomical challenges, the outcomes for patients in our study are quite similar to those reported following pial synangiosis for MMS of a variety of other origins, including idiopathic MMD. Scott and colleagues reported the largest experience with pial synangiosis for MMS in children without SCA. In this series of 143 patients, 68% of whom had preoperative stroke, 7.7% suffered a stroke within 30 days postoperatively, and of 126 patients followed for more than 1 year, 4 suffered a late-onset postoperative stroke. These results suggest that the safety and effectiveness of pial synangiosis for MMS are not decreased in children with SCA.

Detection of MMS in Patients With SCA

A total of 76% of the MSCHONY cohort presented for neurosurgical management with a preexisting neurological deficit. In this group, postoperative progression of neurological symptoms was rare, and ischemic events only occurred in 2 patients postoperatively. Of these cases, only one was a true infarction, and notably this event occurred in the early postoperative period (3 weeks postoperatively) prior to the earliest reported revascularization (6 weeks). Therefore, the timing of this event argues for earlier intervention than for a lack of efficacy of the surgery in this patient. The patient was able to recover all function after this episode and had no subsequent episodes of ischemia. The presented data on reduction of stroke rate suggest that early neurosurgical intervention prior to ischemic episodes and the development of neurological deficits may allow significant improvement in long-term functional outcome in patients with SCA. The median age of patients in our cohort was 12 years, which is nearly 5 years older than the mean treatment age for patients with MMS alone. In 2006 at our institution we began aggressive TCD screening of patients with SCA to ensure early detection of moyamoya-like vasculature. Transcranial Doppler ultrasonography is a noninvasive tool that can be effective as a screening assessment of MMS in patients with SCA. When a child with SCA has elevated velocities on screening TCDs, it is our practice to recommend that pediatric hematologists and neurologists obtain baseline vascular imaging with MRA. If radiographic evidence suggests MMS, we recommend consideration of evaluation by a pediatric neurosurgeon for possible pial synangiosis (Fig. 4). As a result of this protocol, we have successfully performed pial synangiosis procedures on 3 patients with SCA who had significant MMS and evidence of reduced cerebral blood flow, prior to development of stroke.

Conclusions

We have presented a comprehensive review of all reported children with SCA who were treated with pial synangiosis for MMS. Although no direct comparison studies to strictly medical management have been performed, these data compared with historical data suggest that pial synangiosis is a relatively safe operation that may provide a substantial reduction in risk of CVEs. The rate of graft patency and collateralization is high among patients with unilateral and bilateral disease, and progression from unilateral to bilateral disease appears rare. We have instituted early detection and treatment in which TCD screening protocols are used, in the interest of providing long-term maintenance of neurological function and quality of life.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Kennedy, McDowell, Hankinson, Feldstein, Anderson. Acquisition of data: Kennedy, McDowell, Yang, Wilson, Li. Analysis and interpretation of data: Kennedy, McDowell, Yang. Drafting the article: Kennedy, McDowell, Yang, Wilson, Li, Anderson. Critically revising the article: Kennedy, McDowell, Yang, Hankinson, Feldstein, Anderson. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kennedy. Administrative/technical/material support: Kennedy, Anderson. Study supervision: Kennedy, Feldstein, Anderson.

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Manuscript submitted September 15, 2013.
Accepted October 30, 2013.
Please include this information when citing this paper: DOI: 10.3117/2013.10.FOCUS13405.
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