Extracranial-intracranial saphenous vein bypass for carotid or vertebral artery dissections: a report of six cases


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The management of carotid or vertebral artery dissections has generally been either conservative (with anticoagulation) or surgical (by proximal ligation or trapping procedures). However, identification and management of those patients with a high risk of stroke recurrence have been difficult. Six patients with carotid or vertebral artery dissections underwent a total of seven surgical procedures involving intracranial interpositional saphenous vein bypass grafts anastomosed distally beyond the point of dissection with trapping of the intermediate diseased section of the artery. It is suggested that this procedure be used in patients who have bilateral carotid or vertebral artery disease, persistent angiographic abnormalities (particularly aneurysms), or recurring ischemic events while undergoing anticoagulation therapy, or in whom anticoagulation is undesirable. This procedure has benefits over current surgical options because of the maintenance of high flow, the avoidance of abnormal watershed areas of flow, and the elimination of the risk of emboli. The procedure is compared to previous techniques of extracranial-intracranial bypass.

Key Words: arterial dissection · bypass procedure · carotid artery · vertebral artery · saphenous vein graft

Penetration and extension of circulating blood into the wall of a carotid or vertebral artery (“dissection”) have various etiologies. The first traumatic cervical or cephalic arterial dissections were recognized over a century ago and a spontaneous etiology was described 40 years ago. Since these early reports, many cases have been identified and the etiology has been ascribed to trauma, hypertension, fibromuscular dysplasia, Marfan’s syndrome, idiopathic regressing arteriopathy, cystic medial necrosis, and polyarteritis nodosa. The most serious consequence of carotid or vertebral artery dissection is stroke. Traumatic dissections are recognized as being more likely to predispose to stroke. Despite this, both spontaneous and traumatic dissections carry a good prognosis. Options employed to treat dissections include supportive therapy alone, antiplatelet therapy, anticoagulant therapy, and surgery. The surgical options in managing this pathology fall into one of four categories: 1) arterial destructive therapy; 2) direct repair of the dissection; 3) removal of distal emboli; and 4) augmentation of blood flow via bypass procedures. This report presents six patients who underwent a total of seven surgical procedures for internal carotid artery (ICA) or vertebral artery dissections. An intracranial interpositional saphenous vein graft was anastomosed distally to the damaged artery beyond the point of dissection in such a way that the damaged artery was trapped. This procedure is compared with the more common surgical approaches to augment flow by bypass procedures involving a middle cerebral artery (MCA) branch in the anterior circulation. In addition, the approach to management of vertebral dissections via balloon occlusion is reviewed.

The indications for these seven procedures are discussed in terms of defining a group in which an increased risk of stroke can be identified, thus warranting such a surgical approach.

Case Reports
The findings for the six cases described here are summarized in Table 1.
M. K. Morgan and L. H. S. Sekhon

Table 1
Clinical summary of patients with carotid or vertebral artery dissections*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Sex, Age (yrs)</th>
<th>Etiology of Dissection</th>
<th>Vessel(s) Affected</th>
<th>Initial Angiographic Findings</th>
<th>Persisting Stenosis</th>
<th>Persisting Aneurysm</th>
<th>Recurrent Ischemic Episodes</th>
<th>Surgical Procedure</th>
<th>Outcome</th>
<th>Follow-Up Period (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M, 29</td>
<td>traumatic</td>
<td>bilat ICA</td>
<td>Lt: dissection with occlusion; rt: dissection with mild stenosis &amp; aneurysm formation</td>
<td>lt: no; rt: yes</td>
<td>lt: yes</td>
<td>yes</td>
<td>ICA vein bypass</td>
<td>good; postop epidural hematoma, recovered with no sequelae</td>
<td>lt: 33; rt: 22</td>
</tr>
<tr>
<td>2</td>
<td>M, 39</td>
<td>?traumatic</td>
<td>rt VA</td>
<td>dissection with aneurysm formation</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>rt VA vein bypass</td>
<td>excellent</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>M, 9</td>
<td>traumatic</td>
<td>bilat VA</td>
<td>rt: occlusion; lt: dissection; basilar artery embolus</td>
<td>lt: no; rt: yes</td>
<td>no</td>
<td>yes</td>
<td>rt VA vein bypass</td>
<td>good; propr defects improving</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>M, 36</td>
<td>spontaneous</td>
<td>lt ICA</td>
<td>marked stenosis with slow flow</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>ICA vein bypass</td>
<td>excellent</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>F, 36</td>
<td>traumatic</td>
<td>bilat ICA</td>
<td>lt: dissection, aneurysm formation, &amp; fistula; rt: dissection</td>
<td>NA</td>
<td>NA</td>
<td>no</td>
<td>ICA vein bypass</td>
<td>excellent</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>F, 53</td>
<td>spontaneous</td>
<td>bilat ICA</td>
<td>bilateral high-grade stenoses from dissection</td>
<td>NA</td>
<td>NA</td>
<td>no</td>
<td>ICA vein bypass</td>
<td>excellent</td>
<td>2</td>
</tr>
</tbody>
</table>

*ICA = internal carotid artery; VA = vertebral artery; NA = not applicable.

Case 1

This 29-year-old man was involved in a motorcycle accident, resulting in multiple injuries but no significant head injury or neurological deficit. He was discharged from his local hospital 4 weeks after the accident, apparently fully recovered. Seven weeks after the accident, he presented with drowsiness, aphasia, a right hemiplegia, and left Horner’s syndrome.

Examination. A brain computerized tomography (CT) scan confirmed early left MCA infarction. Cerebral angiography disclosed bilateral high cervical ICA dissections with occlusion on the left, mild stenosis and aneurysm formation on the right, and spontaneous cross-filling of the left MCA from the right. The patient was initially managed conservatively, was subsequently anticoagulated, and progressed well. Four months after the stroke, repeat angiography demonstrated no change to the right ICA dissection and recanalization of the left ICA, with marked aneurysmal dilatation of this vessel at the C-1 level (Fig. 1a and b). He suffered a left MCA transient ischemic attack (TIA) 24 hours after the angiogram despite full anticoagulation with heparin. As a result, it was decided that surgical intervention should be attempted.

First Operation. Four months after the stroke, an interpositional saphenous vein bypass graft was placed between the left common carotid artery and the left intracranial ICA. The distal anastomosis was end-to-end and placed between the ophthalmic and the posterior communicating arteries, with an aneurysm clip securing the free end of the ICA. The proximal anastomosis was end-to-side on the common carotid artery, after which the origin of the ICA was ligated. During the bypass procedure, electroencephalographic (EEG) monitoring guided cerebral protection. Postoperatively, the patient was neurologically unchanged. Because of the perceived risk of stroke from the right ICA, heparin infusion was recommenced 4 days after surgery. Shortly after this time, he complained of severe headache and a CT scan revealed an epidural hematoma. The hematoma was evacuated and anticoagulation was delayed. Neither the hematoma nor the surgery resulted in neurological compromise.

Repeat angiography demonstrated the interpositional graft to be patent. Twelve months after the initial surgery, good recovery from the stroke had been made, with only a mild expressive dysphasia persisting. Repeat cerebral angiography again confirmed patency of the graft and a persisting false aneurysm of the right ICA that had not changed substantially since the original angiogram.

Second Operation. Because of the presence of a persisting aneurysm and the risks of long-term anticoagulation, prophylactic surgery was again considered. An interpositional saphenous vein bypass graft between the right common carotid artery and the right intracranial ICA was performed in the same way as that on the left.

Postoperative Course. There were no postoperative problems and angiography confirmed graft patency (Fig. 1c and d). Repeat angiography 6 months later confirmed graft patency. With the patient on a course of aspirin alone, no ischemic events had occurred during the 33-month follow-up period for the left bypass graft and the 22-month follow-up period for the right bypass graft.

Case 2

This 39-year-old man was well prior to presentation with a submaximal infarction in the distribution of right
posterior inferior cerebral artery territory. He had undergone chiropractic neck manipulation 4 months beforehand. He had no risk factors for cerebrovascular disease.

Examination. Cerebral angiography demonstrated a right vertebral artery dissection with aneurysm formation at the C-1 level (Fig. 2 left). The patient recovered fully from the stroke and was anticoagulated. Six months following the original angiogram, repeat angiography disclosed persistence of the false aneurysm. Persistence of the aneurysm coupled with a positive balloon occlusion test on angiography prompted consideration of surgical intervention.

Operation. The right vertebral artery was exposed from the C-2 level to the origin of the posterior inferior cerebellar artery via a posterior approach under somatosensory evoked potential (SSEP) and EEG monitoring. Fusiform dilatation from the foramen transversarium of C-1 to the point of dural penetration was apparent, clearly indicating that the length affected was far greater than that suggested on the angiogram. An interpositional saphenous vein graft was anastomosed end-to-end between the right vertebral artery at the C-2 level and this same artery at the point of its dural penetration. The pathology of the abnormal artery confirmed the presence of dissection and the absence of other arterial disease.

Postoperative Course. No complications ensued and the patient was discharged home without deficit on a low-dose course of aspirin. Follow-up angiography at 4 months demonstrated a well-functioning bypass (Fig. 2 right). No ischemic episodes have occurred in the 16 months since surgery.

Case 3

This 9-year-old boy was well until he fell awkwardly while playing on a trampoline. At that time, he developed left facial weakness, spastic quadriplegia, and bulbar dysfunction which improved over a period of 3 weeks. Two months later he suffered a similar
episode, after which he remained vertiginous and complained of persisting headache.

Examination. A diagnosis of brain-stem ischemia was made and a magnetic resonance (MR) image confirmed brain-stem infarction. Cerebral angiography demonstrated complete occlusion of the right vertebral artery from its origin to the level of the C1–2 articulation, at which point antegrade vertebral flow was completed by small collateral vessels from the right costocervical trunk (Fig. 3 left). The left vertebral artery, while widely patent, had a minor abnormality at the C1–2 level suggestive of dissection, and the basilar apex had a small filling defect perhaps relating to a previous embolus. A diagnosis of posterior circulation ischemia secondary to bilateral vertebral artery dissection was now thought to be responsible for both of the child’s previous neurological episodes.

The patient was fully anticoagulated but, despite careful hematological management, he continued to experience transient posterior circulation ischemic episodes, including episodes of complete blindness and of feeling locked-in. In all, the child experienced 14 TIA’s of increasing frequency over a 14-month period. Repeat angiography demonstrated no change in the anatomy except for resolution of the abnormality at the basilar apex. Because the TIA’s persisted despite full anticoagulation, surgical intervention was decided upon.

Operation. Fifteen months after the child’s fall, he underwent surgery with SSEP monitoring. With the patient in the park-bench position with the right side uppermost, the neck turned to the left, and the head flexed, both an anterior sternomastoid incision for carotid exposure and a posterior approach for a foramen magnum decompression were made. An interpositional saphenous vein graft was placed between the right common carotid artery (end-to-side anastomosis) and the right vertebral artery (end-to-end anastomosis). The distal anastomosis was made at the point of dural penetration of this vessel.

Postoperative Course. Recovery was uncomplicated except for the development of hydrocephalus necessitating shunting. Angiography at 1 month postsurgery confirmed that the bypass graft was functioning well (Fig. 3 right). The patient was discharged on a low-dose course of aspirin and, at follow-up examination, had achieved a reasonable recovery from the original stroke. At 15 months postsurgery, he has had no further ischemic events; his most significant residual problem was dysarthria, although the could be understood.

Case 4

This 36-year-old man sustained a submaximal completed stroke in the left MCA territory rendering him dysphasic and hemiplegic. There were no known risk factors and trauma was not implicated.

Examination. The patient was initially investigated with CT and carotid duplex ultrasound studies. A left posterior frontocortical infarct and a high-grade stenosis of the left ICA were demonstrated. Initial management was full anticoagulation. He commenced to recover but 10 days later suffered a TIA in the same territory as the stroke. Anticoagulation therapy was continued until further investigation 3 months later with cerebral angiography. At that time, it was found that the left ICA continued to have a marked stenosis. Left common carotid angiography revealed marked slow flow, and spontaneous cross-filling occurred from injection of the right common carotid artery (Fig. 4 left and center). No other abnormality was present. A presumptive diagnosis of spontaneous left ICA dissection was made.

Operation. Because of the high-grade stenosis and the patient’s clinical course (including a TIA while he was anticoagulated), surgery was considered. At the time of surgery, his neurological deficits had improved considerably. He underwent placement of an interpositional saphenous vein bypass graft between the left common carotid artery and the left intracranial ICA. The distal anastomosis was end-to-end and placed between the ophthalmic and the posterior communicating arteries, with an aneurysm clip securing the free end of the ICA. The proximal anastomosis was end-to-side on the common carotid artery. During the bypass procedure, EEG monitoring guided cerebral protection. No perioperative problems occurred.

Postoperative Course. The patient was discharged on a low-dose course of aspirin and he has been without evidence of retinal or hemispheric ischemic events during the 9 months since surgery. Postoperative angiography confirmed graft patency (Fig. 4 right).
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Case 5

This 36-year-old woman was involved in a motor-vehicle accident, resulting in admission to the hospital for management of a burst fracture at L-2 and a fractured sternum with bilateral lung contusions. No head or neck injury was sustained.

Examination. From the time of admission, the patient complained of paresthesia over her left cheek; however, neurological examination was normal. A CT scan of the head was normal but a carotid duplex ultrasound study suggested a left ICA dissection. Subsequent angiography 1 week later revealed bilateral dissections of the ICA's at the C-2 level. On the left side, aneurysm formation was evident, and intracranial extension of the dissection was apparent because of the presence of a small carotid-cavernous fistula (Fig. 5 left). Neither side had significant stenosis, and a balloon occlusion test of the left ICA was satisfactory. However, because both ICA's were involved and progression of traumatic dissection may occur in as many as 36% of arteries, definitive surgical bypass of the left side was considered to be the most appropriate course of action.

Operation. The patient underwent an interposition saphenous vein bypass graft procedure between the left common carotid artery and the left intracranial ICA. The distal anastomosis was end-to-end and placed between the ophthalmic and the posterior communicating arteries, with an aneurysm clip securing the free end of the ICA. The proximal anastomosis was end-to-side on the common carotid artery. During the bypass procedure, EEG monitoring guided cerebral protection. No perioperative problems occurred.

Postoperative Course. The patient has been well without retinal or hemispheric ischemic events in the

Fig. 4. Case 4. Left and Center: Preoperative left internal carotid angiograms. Early arterial phase angiogram (left) demonstrating high-grade stenosis and late arterial phase angiogram (center) demonstrating continuity of flow in the vessel. Right: Postoperative left lateral common carotid angiogram demonstrating a functioning interposition saphenous vein bypass graft between the left common carotid artery and the left internal carotid artery.

Fig. 5. Case 5. Left: Preoperative left common carotid angiogram demonstrating the traumatic dissecting aneurysm. Right: Postoperative left common carotid angiogram showing patency of the interpositional saphenous vein graft between the left common carotid artery and the left internal carotid artery.
followed in studies. Artery; difficulty prior with CT progression persisting recanalized occlusion acute stroke no. 

~: "J" * Reported by Mokri and colleagues.5,13,37 ICA = internal carotid artery; VA = vertebral artery.
† As indicated on follow-up angiograms in patients undergoing repeat studies.
‡ "Focal cerebral ischemic symptoms ... usually were delayed and followed a headache by a period ranging from a few minutes to 2 weeks."
§ Headache preceded stroke by 5 hours to 2 weeks.
‖ All late strokes in patients with traumatic ICA dissections occurred in patients with persisting aneurysms.

8 months since surgery. Postoperative angiography confirmed graft patency (Fig. 5 right).

**Case 6**

This 53-year-old hypertensive woman presented with a 2-week history of occipital headache. The day prior to presentation, she had several episodes of difficulty in finding words.

**Examination.** Investigations performed included a CT head scan which showed no abnormalities, an EEG assessment which showed bilateral slowing (more marked on the left), and cerebral angiography. The cerebral angiogram revealed bilateral ICA dissections immediately beneath the skull base with a 90% stenosis on the right and a 99% stenosis on the left (Fig. 6 left and center). A temporary balloon occlusion test suggested that occlusion of the left ICA could be tolerated for a short time.

**Operation.** Because of the severity of the bilateral ICA stenosis and the fear that progression would result in a major infarction, a left common carotid artery-ICA bypass with an interpositional saphenous vein graft was performed in the same way as in Cases 1, 4, and 5. No perioperative morbidity occurred.

**Postoperative Course.** A postoperative angiogram demonstrated a well-functioning bypass (Fig. 6 right). During the 2 months since surgery, no retinal or hemispheric symptoms have ensued.

**Discussion**

**Natural History**

The prognosis for patients with vertebral and carotid artery dissection is in general very good. Early review papers suggested a much poorer prognosis but failed to shed light on the true natural history of the disease because of the tendency to report pathological studies.39 More recently, reports of both a benign outcome and spontaneous arterial repair are on record, suggesting that long-term prognosis may indeed be excellent.1,13,17,25,30,31,35,41,43 Several series have now confirmed the suggestion from these isolated case reports that the majority of patients do well;23,34,35,37 the experience at the Mayo Clinic indicates that 85% of patients with spontaneous ICA dissection make a complete recovery, with angiographic improvement

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**TABLE 2**

Mayo Clinic experience with arterial dissections

<table>
<thead>
<tr>
<th>Event</th>
<th>Arterial Dissection</th>
<th>Spontaneous ICA</th>
<th>Traumatic ICA</th>
<th>Spontaneous VA</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of cases</td>
<td>70</td>
<td>21</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>stroke</td>
<td>27%</td>
<td>62%</td>
<td>48%</td>
<td></td>
</tr>
<tr>
<td>delayed strokes</td>
<td>3%</td>
<td>100%</td>
<td>83%‡</td>
<td></td>
</tr>
<tr>
<td>stroke after 20 days</td>
<td>0%</td>
<td>24%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>acute occlusion</td>
<td>17%</td>
<td>28%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>recanalized occlusion</td>
<td>1 of 7</td>
<td>0 of 5</td>
<td>2 of 3</td>
<td></td>
</tr>
<tr>
<td>persisting stenosis</td>
<td>19%</td>
<td>41%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>occlusion †</td>
<td>12%</td>
<td>23%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>persisting aneurysm †</td>
<td>12%</td>
<td>23%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>progression of stenosis †</td>
<td>10%</td>
<td>36%</td>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

* Reported by Mokri and colleagues.5,13,37 ICA = internal carotid artery; VA = vertebral artery.
† As indicated on follow-up angiograms in patients undergoing repeat studies.
‡ "Focal cerebral ischemic symptoms ... usually were delayed and followed a headache by a period ranging from a few minutes to 2 weeks."
§ Headache preceded stroke by 5 hours to 2 weeks.
‖ All late strokes in patients with traumatic ICA dissections occurred in patients with persisting aneurysms.
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expected in 60% of aneurysms and 87% of stenoses. For traumatic ICA dissections, 71% of patients make an excellent recovery, with angiographic improvement in 21% of aneurysms and 55% of stenoses.14 Spontaneous dissections of the vertebral artery were associated with a good outcome in 88% of patients and an angiographic improvement in 76%.14

Despite optimism with regard to outcome, there does remain a significant incidence of poor results from arterial dissections, prompting a need to reflect upon possible improvements in management. The Mayo Clinic experience indicates that the risk for stroke with spontaneous dissection of the ICA is 27%, spontaneous dissection of the vertebral artery 48%, and traumatic ICA dissection 62%.34,35 (Table 2). The stroke onset was usually delayed following the initial symptom or trauma. This presents a window of opportunity for stroke prophylaxis. Furthermore, the contribution of dissection to the incidence of strokes in the community has been studied and found to be significant: 2.5% of all first strokes are caused by dissections1 and, in patients under 41 years of age, the figure is 10% to 20%.16,28 Thus, the importance of stroke complicating arterial dissection cannot be underestimated. In our series, the significance of the stroke suffered was profound, with permanent neurological deficit in three of the four patients sustaining stroke.

The interval between trauma or the classic presentation of spontaneous dissection (hemiphenal headache and a Horner’s syndrome) and stroke for ICA dissection is also important. As recognition of the arterial damage may allow for effective intervention. In our Case 1 there was a 7-week interval between trauma and stroke, of which 4 weeks were spent in the hospital, allowing an opportunity for diagnosis prior to stroke had appropriate investigations been performed. In the other two cases of severe stroke (Cases 3 and 4), while a delay occurred between trauma and stroke, it is not likely that the symptoms prior to stroke would alert one to the impending catastrophe. However, our experience suggests that at least some strokes could be prevented if appropriate therapy is applied during this window of opportunity.

Identifiable risk factors for the prediction of stroke have hitherto not been addressed, with the exception that Mokri24 found a tendency for traumatic dissections to fare worse than spontaneous dissections. Reviewing angiograms from these two groups of dissections, there was a significant difference in terms of the tendency for improvement in either stenosis or aneurysm formation (Table 2); the traumatically induced lesions were less likely to heal. All patients who suffered delayed strokes had persisting angiographic abnormalities (aneurysms in all cases).27 In Mokri’s study, both patients who died early after trauma had sustained carotid artery occlusions and formed a subset within the group of five patients with traumatic carotid occlusions. Our interpretation of these results is that severe and persisting angiographic abnormalities are likely to increase the risk of stroke. Furthermore, persisting aneurysms may be particularly dangerous, and thus the presence of any of these features may well be indications for surgical intervention.

Treatment

It is recognized that the majority of strokes arise as a consequence of embolization. Antiplatelet or anticoagulation therapy has been used in arterial dissections for stroke prophylaxis, but a comprehensive trial of this treatment has not yet been performed. If healing of the arterial dissection is expected to occur relatively quickly, then the risks of anticoagulation are present only in the short term. Healing can be expected to be rapid in approximately 60% of aneurysms and 80% to 90% of stenoses caused by spontaneous ICA or vertebral artery dissections. For traumatic ICA dissections, healing is rapid in 50% with stenosis and 20% with aneurysms.34,35,37 When healing does not occur quickly or fails to occur at all, the risk of stroke persists (at least in the traumatic aneurysm group), as is illustrated by the subsequent development of stroke as late as 6 to 10 years in the series of Mokri et al.37 The risk of late stroke may have been understated in this series, as 44% of patients underwent surgery for stroke prophylaxis. Because of the persisting long-term stroke risk, long-term anticoagulation in relatively young patients needs to be carefully contemplated. The inherent risks of hemorrhage (2% per year35), the possibility of complications during obstetric and medical episodes, the requirements for the development of dependence on medical personnel for monitoring, the direct and indirect financial costs of this form of therapy, and the dietary restrictions all need to be considered before long-term anticoagulation is embarked upon. Thus, long-term anticoagulation may be an unacceptable option if a reasonable alternative exists. It is uncertain whether a course of aspirin would offer stroke prophylaxis in the case of traumatic dissections that fail to heal. As a result, surgical intervention should be considered in younger patients if long-term anticoagulation is undesirable. The four surgical options employed for stroke prophylaxis include arterial lesion destruction, direct repair of the dissection, removal of distal emboli, and augmentation of blood flow via techniques that bypass the diseased segment in addition to trapping the diseased segment.

Obliteration of the source of emboli by either proximal ligation or trapping procedures has been reported to be effective in the treatment of both anterior and posterior circulation dissection.7,15,23,42,51,54,56,57 However, despite apparently adequate assessment of the collateral circulation in these series, there is a 16% incidence of stroke in the posterior circulation with vertebral artery ligation40,55 and, even with a balloon occlusion test, 5% to 20% will subsequently develop an infarction with permanent carotid artery occlusion.2,18,46 Therefore, the selection of patients for this form of vascular ablative therapy has proven to be difficult. Furthermore, the prevalence of contralateral arterial involvement (four of six cases in our surgical series and 29% to 40% in the experience of Mokri and
colleagues\textsuperscript{34,35,37} brings this treatment into question in the absence of bypass precautions, since there is a definite risk of progression of stenosis, even to the point of occlusion. In the series of Mokri and coworkers\textsuperscript{34,35,37} the documented angiographic progression of stenosis was 10\% for spontaneous ICA dissections, 15\% for spontaneous vertebral artery dissections, and 36\% for traumatic ICA dissections. These figures are retrospective and may overstate the problem but, nevertheless, progression clearly does occur. Not only does the concern with potential progression raise doubts with regard to the safety of therapeutic ligation when bilateral involvement is observed, but it also cautions against a conservative approach when a progression in one artery may not be compensated due to a contralateral diseased artery. This argument prompted the decision for early surgery in our Cases 5 and 6. Finally, the long-term future of young patients who have undergone a substantial reduction in collateral flow to the circle of Willis must be of concern. In view of these pitfalls of ligation or trapping procedures, consideration should be given to flow augmentation.

Augmentation of blood flow by bypass procedures has been used as a therapeutic option for carotid artery dissection.\textsuperscript{5,19} The rationale for this treatment in combination with trapping of the arterial segment (considered to be a continual threat of emboli) would seem to be soundly based on the physiological principles of eliminating the source of embolic stroke while not reducing the hemodynamic reserve. However, since the results of the EC/IC (extracranial/intracranial) Bypass Study Group\textsuperscript{16} demonstrated that superficial temporal artery anastomosis to the MCA did not effectively prevent cerebral ischemia in patients with atherosclerotic disease in the carotid and middle cerebral arteries, this treatment has fallen out of favor. Concerns have been raised with regard to the recruitment and admission criteria to the trial as well as questions regarding the conclusions reached.\textsuperscript{47,48} The generalization from this study that EC/IC bypass procedures of all types are ineffective in stroke prophylaxis may also be incorrect. There are many variations of the bypass procedure that involve varying volumes and direction of flow. The superficial temporal artery anastomosis to an MCA branch is a low-volume conduit, initially delivering only 30 ml/min with the capacity to increase over time but rarely to the point of supplying all of the MCA territory.\textsuperscript{36} Furthermore, the watershed between the territory supplied by the superficial temporal artery and that of the natural circulation may thrombose as a result of stasis; as a consequence of this, infarction may ensue.\textsuperscript{32,33,13,14,21,32,33} In comparison to the relatively low flows resulting from superficial temporal artery anastomosis to an MCA branch, interpositional venous grafts between a major cervical artery and a large intracranial artery offer the potential for much higher flows and a different watershed point. Sundt, et al.\textsuperscript{49} reported that, when an interpositional saphenous vein graft was used between the common or external carotid artery and the M\textsubscript{1} segment, average graft flow was 100 ml/min; when the recipient vessel was the posterior cerebral artery, mean graft flow was 110 ml/min. It is likely that flow could be even higher if the distal anastomosis is more proximally placed, as the venous conduit is usually much larger than the recipient vessel.\textsuperscript{49} The aim of bypass grafts in our patients was to provide high flow and avoid an abnormal watershed area that could act as a nidus for thrombus formation. The five anterior circulation grafts were distally anastomosed end-to-end to the ICA proximal to the posterior communicating artery and provided flow to the entire ipsilateral MCA and anterior cerebral arteries. This is clearly of great importance when bilateral common carotid artery-intracranial ICA bypass was performed. Similarly, the two distal anastomoses of the posterior circulation grafts were performed as proximally as possible on the vertebral artery, ensuring that they were free of dissected artery and that they could carry a high flow and avoid abnormal watershed regions. There is little to equate this type of bypass with superficial temporal artery anastomosis to an MCA branch and therefore there is no reason to extrapolate the lack of efficacy reported by the EC/IC Bypass Study Group to these larger, more proximal grafts. The problems with the interpositional common carotid artery-intracranial ICA saphenous vein graft are the time required for anastomosis and the invasiveness of the cranial surgery. Because it is necessary to interrupt flow in the ICA for approximately 60 minutes (to place a temporary clip on the posterior communicating artery in order to gain the necessary length of ICA for anastomosis), collateral flow is nearly entirely dependent upon the anterior cerebral arteries and their communicator. For this reason, we routinely perform a balloon occlusion test angiogram in patent arteries for 30 minutes with EEG monitoring prior to surgery. If this test balloon occlusion is successful and significant collateral flow is derived from the contralateral ICA, we feel comfortable performing the bypass under heparinization, with barbiturates reserved for use only if EEG slowing becomes apparent. If the temporary balloon occlusion fails (which did not occur in our series) and surgery remains warranted, it may be necessary to perform such surgery with the cerebral protection of deep hypothermia. The argument that a patient tolerating the cross-clamp time of 60 minutes does not require a bypass is fallacious, as the cause of delayed stroke in this condition is usually embolic in nature.\textsuperscript{34,37} The end-to-end distal anastomosis eliminates redundant artery that may potentially act as a source of emboli.

The nonischemic risks of the procedure are primarily those of a pterional craniotomy, removal of the anterior clinoid process, and either a wide sylvian split for the anterior circulation or a wide posterior fossa approach in the case of vertebral artery surgery. We believe that these risks are very small in an otherwise healthy patient as is usually the case in patients with this condition. Exposure of the distal anastomosis can be obtained with minimum or no retraction, thus limiting this source of morbidity. Lumbar cerebrospinal fluid (CSF) drainage is not usually necessary to aid relaxation but it is useful in minimizing the amount of CSF that en-
EC-IC saphenous vein bypass for artery dissections

devlops the site of anastomosis while this surgery is being performed. The use of heparin during the anasto-
omosis may slightly increase the risk of hemorrhagic complications, but we have not found it to be a problem if the heparin is fully reversed at the completion of surgery. In the one patient who developed a postop-
erative hematoma (Case 1), we believe that the early reintroduction of anticoagulation was responsible and that this practice is not indicated unless the contralateral artery is symptomatic, in which case we would recom-
mand the use of Fragmin (low-molecular-weight heparin sodium).

Conclusions

The natural history of a carotid or vertebral artery dissection is for the most part benign. It is, however, possible to identify a group of patients with a higher risk of stroke and, for these patients, stroke prophylaxis can be offered. The six cases presented demonstrate one surgical approach to such prophylaxis. Consideration should be given to surgery when a dissection involves bilateral internal carotid or vertebral arteries, where ischemic episodes continue while the patient is ade-
quately anticoagulated, where aneurysm (particu-
larly if traumatic in origin) persists unaltered for more than 3 months, or where long-term anticoagulation is an unacceptable option. The surgical treatment for ICA dissection includes trapping of the damaged arterial segment along with an interposition saphenous vein graft from the common carotid artery to the intracranial ICA, performing an end-to-end anastomosis on the ICA between the ophthalmic artery and the posterior com-
municating artery. In the case of vertebral artery dis-
section, a distal end-to-end anastomosis near the dural penetration and a proximal anastomosis either on the common carotid or on the proximal vertebral artery are the goals. We believe these procedures to be safe and effective in eliminating emboli, in providing a high flow, and in eliminating abnormal watershed areas of flow that may complicate other EC/IC bypass pro-
dures and, as a result, be superior to any comparable procedure.

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