Aneurysms of the intracavernous carotid artery: a multidisciplinary approach to treatment

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Of 43 cavernous sinus aneurysms diagnosed over 6½ years, 23 fulfilled indications for treatment; of these 19 were treated, eight surgically and 11 with interventional radiological techniques. Six small and two giant aneurysms were treated surgically; four were clipped, two were repaired primarily, and two were trapped with placement of a saphenous-vein bypass graft. Seven large and four giant aneurysms were treated with interventional radiological techniques: in five cases the proximal internal carotid artery (ICA) was sacrificed; one aneurysm was trapped with detachable balloons; and five were embolized with preservation of the ICA lumen. The mean follow-up period was 25 months. At follow-up examination, three patients in the surgical group were asymptomatic, two had improved, and three had worsened. Three of these patients had asymptomatic infarctions apparent on computerized tomography (CT) scans. At follow-up examination, four radiologically treated patients were asymptomatic, five had improved, two were unchanged, and none had worsened. One patient had asymptomatic and one minimally symptomatic infarction apparent on CT scans; both lesions were embolic foci after aneurysm embolization with preservation of the ICA.

It is concluded that treatment risk depends more on the adequacy of collateral circulation than on the size of the aneurysm. A multidisciplinary treatment protocol for these aneurysms is described, dividing patients into high-, moderate-, and low-risk groups based on pretreatment evaluation of the risk of temporary or permanent ICA occlusion using a clinical balloon test occlusion coupled with an ICA-occluded stable xenon/CT cerebral blood flow study. Radiological techniques are suggested for most low-risk patients, while direct surgical techniques are proposed for most moderate- and high-risk patients.

Key Words: cavernous sinus • aneurysm • revascularization • embolization • internal carotid artery

Not long ago, intracavernous carotid artery aneurysms could be treated only by cervical carotid artery ligation with or without extracranial-intracranial bypass, or by direct surgical repair with cardiac standstill. The rapid and simultaneous development of interventional radiological balloon catheter techniques as well as improved direct surgical approaches to the cavernous sinus 11-13, 36, 40-43 have significantly expanded our therapeutic armamentarium for these lesions.

Several recent papers have reported acceptable results obtained by treating cavernous sinus aneurysms with balloon occlusion of the internal carotid artery (ICA) proximal to the aneurysm or with balloon embolization of the aneurysm lumen and preservation of the ipsilateral ICA. Others have described favorable outcomes in patients treated with direct surgical approaches for clipping, aneurysmorrhaphy, or cavernous sinus trapping with saphenous-vein bypass grafting. What has not been addressed is how these various procedures relate to one another in determining the best treatment for any given patient with an intracavernous carotid artery aneurysm. In this paper, we present our experience in treating cavernous sinus aneurysms over the last 6½ years using either surgical or interventional radiological techniques. Based on our experience and an extensive literature review, we propose a multidisciplinary treatment protocol for intracavernous carotid artery aneurysms. The rationale supporting the treatment protocol is critically discussed.

Clinical Material and Methods

An aneurysm was considered to be intracavernous if it was shown by angiography to arise proximal to the ophthalmic artery. We also included aneurysms at or distal to the ophthalmic artery but found intraopera-
tively to arise completely within the cavernous sinus. Aneurysms arising outside the cavernous sinus but with part of their sac extending into the cavernous sinus were excluded. The more common extracavernous "paracavernous" aneurysms that required entry into the cavernous sinus at surgery to facilitate clip placement were also excluded.

Between January, 1984, and June, 1990, 43 intracavernous carotid artery aneurysms were diagnosed in 36 patients at our institution. The indications for treat-ment of idiopathic cavernous sinus aneurysms currently accepted at our institution are based on a retrospective study of the natural history of cavernous sinus aneurysms. Treatment of asymptomatic idiopathic cavernous sinus aneurysms is reserved for patients whose aneurysm extends into the subarachnoid space or arises from the anterior genu of the cavernous ICA, since both of these circumstances are associated with a risk of subarachnoid hemorrhage (SAH). Treatment in symptomatc idiopathic patients is reserved for those with progressive ophthalmoplegia or visual loss, those with severe ipsilateral facial or orbital pain, those who demonstrate aneurysm enlargement based on imaging criteria, and those with epistaxis or SAH. Aneurysms that did not meet these criteria continue to be followed without treatment. Twenty-three of the 43 cavernous sinus aneurysms met indications for treatment.

Each of the 23 patients underwent pretreatment evaluation of the risk of temporary or permanent ipsilateral ICA occlusion using a 15-minute clinical balloon test occlusion. If the patient tolerated the balloon test occlusion without neurological deficit, then stable xenon/computerized tomography cerebral blood flow (Xe/CT CBF) studies were performed, first with the balloon occluding the ipsilateral ICA, then with the balloon deflated. The technical details of performing both procedures have been described previously.

The balloon test occlusion and Xe/CT CBF evaluation enabled division of the patients into three groups. Patients who tolerated the clinical balloon test occlusion and had an ICA-occluded cerebral blood flow (CBF) greater than 30 ml/100 gm/min were placed in the low-risk group. Patients who tolerated the balloon test occlusion but had an ICA-occluded CBF of 30 ml/100 gm/min or less made up the moderate-risk group. With the balloon inflated, these patients typically showed an asymmetrical decrease in CBF, worse on the occluded side. Patients who clinically failed the balloon test occlusion constituted the high-risk group.

Of the 23 aneurysms that met indications for treatment, four were in patients considered high risk based on their balloon test occlusion-Xe/CT CBF evaluation. Of these four, two had treatment deferred, one was clipped, and one was trapped surgically with placement of a petrosal-to-supraclinoid ICA saphenous-vein bypass graft. Three aneurysms were in moderate-risk patients; one was embolized with preservation of the ICA lumen and one was trapped surgically with placement of a petrosal-to-supraclinoid ICA saphenous-vein bypass graft. The third patient with an aneurysm in the moderate-risk category refused further treatment after an embolization attempt failed. Sixteen aneurysms were in low-risk patients; of these, three were clipped, two underwent aneurysmorrhaphy, four were embolized with preservation of the ICA lumen, one was trapped between detachable balloons, five were treated by detachable balloon occlusion of the proximal ipsilateral ICA, and one was subsequently treated surgically at another hospital after a proximal ICA balloon occlusion attempt failed. Overall, eight aneurysms were treated surgically and 11 with interventional radiological techniques. The mean clinical follow-up period (± standard deviation) for treated cavernous sinus aneurysms was 25 ± 18 months.

A description of the specific surgical techniques employed has been published previously. In all cases we monitored the cavernous sinus cranial nerves with intraoperative electromyography and the hemispheric function during carotid occlusion with somatosensory evoked potential (SSEP) recording.

The interventional radiographical techniques were similar to those previously described by others. We performed all proximal ICA occlusions using detachable balloons supplemented in one case with Gianturco coils. We performed all intra-aneurysm embolizations with detachable balloons. In all but one case, the patient was awake.

Results

Surgical Procedures

A clinical summary listing the aneurysm characteristics, treatment indications, treatment chosen, clinical outcome, and treatment complications for the eight surgically treated patients is presented in Table 1. The mean patient age was 47 ± 14 years. The aneurysm was clipped in four cases (Fig. 1) and repaired primarily (aneurysmorrhaphy) in two cases; in the other two cases the cavernous ICA was trapped, with construction of a saphenous-vein bypass from the petrous to the supraclinoid ICA (Fig. 2). There was no surgical mortality. At follow-up examination, three patients were asymptomatic, two had improved symptomatically from their preoperative condition, and three had worsened slightly.

Computerized tomography (CT) revealed three postoperative infarctions. In Case 23, the balloon test occlusion led to an ipsilateral ICA dissection with delayed embolization to the M, segment of the middle cerebral artery (MCA), resulting in aphasia and a contralateral hemiparesis. An emergency embolectomy and aneurysmorrhaphy of the cavernous sinus aneurysm left the patient with an asymptomatic small putamen infarction.
Intracavernous carotid artery aneurysms

TABLE I
Clinical summary of surgically treated intracavernous aneurysms in eight patients

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Type of Aneurysm</th>
<th>Size</th>
<th>Indications</th>
<th>Treatment</th>
<th>Risk Group</th>
<th>Outcome</th>
<th>Residual Deficit (new deficit)</th>
<th>Complications</th>
<th>Radiographic Follow-Up</th>
<th>Clinical Follow-Up (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>66</td>
<td>F</td>
<td>spontaneous</td>
<td>small</td>
<td>subarachnoid</td>
<td>clipping</td>
<td>low</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td>17 mos</td>
<td>25</td>
</tr>
<tr>
<td>14</td>
<td>33</td>
<td>F</td>
<td>traumatic</td>
<td>small</td>
<td>subarachnoid</td>
<td>clipping</td>
<td>low</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td>5 days</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>59</td>
<td>F</td>
<td>spontaneous</td>
<td>small</td>
<td>subarachnoid</td>
<td>clipping</td>
<td>high</td>
<td>worse</td>
<td>(decreased vision, partial III)</td>
<td>none</td>
<td>14 days</td>
<td>21</td>
</tr>
<tr>
<td>17</td>
<td>31</td>
<td>F</td>
<td>spontaneous</td>
<td>small</td>
<td>SAH, orbital pain</td>
<td>clipping</td>
<td>low</td>
<td>improved</td>
<td>Horner's syndrome, partial VI</td>
<td>none</td>
<td>5 days</td>
<td>22</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
<td>F</td>
<td>spontaneous</td>
<td>small</td>
<td>subarachnoid</td>
<td>clipping</td>
<td>low</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td>5 days</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>45</td>
<td>F</td>
<td>spontaneous</td>
<td>giant</td>
<td>orbital pain</td>
<td>clipping</td>
<td>low</td>
<td>poor</td>
<td>(partial III) partial V</td>
<td>small putamen infarction</td>
<td>14 days</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>F</td>
<td>spontaneous</td>
<td>small</td>
<td>subarachnoid</td>
<td>trapping</td>
<td>high</td>
<td>worse</td>
<td>(partial V, dry eye, partial III)</td>
<td>watershed infarctions</td>
<td>14 mos</td>
<td>24</td>
</tr>
<tr>
<td>7§</td>
<td>68</td>
<td>F</td>
<td>spontaneous</td>
<td>giant</td>
<td>orbital pain, progressive ophthalmoplegia</td>
<td>clipping</td>
<td>low</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td>5 days</td>
<td>6</td>
</tr>
</tbody>
</table>

*Abbreviations: SAH = subarachnoid hemorrhage; asympt = asymptomatic; P-S = petrosal-to-supraclinoid intracranial carotid artery saphenous-vein bypass. Roman numerals denote cranial nerve palsy.
† Small: < 1 cm diameter; large: 1 to 2.5 cm in diameter; giant > 2.5 cm in diameter.
‡ Incidental cavernous sinus aneurysms which communicated with the subarachnoid space after surgical dissection for tumor removal.
§ Died of a postmortem-confirmed myocardial infarction 4 months after surgery; bypass graft patent.

visible on CT scanning. This was the only case of ICA dissection leading to embolization in over 300 balloon test occlusions performed thus far at our institution. In Case 4, a patient who had a traumatic cavernous sinus aneurysm with severe epistaxis failed the clinical balloon test occlusion and her hemiparesis did not completely resolve after balloon deflation; the cavernous ICA was trapped, and a petrosal-to-supraclinoid ICA bypass was placed with induced hypertension during temporary occlusion. Barbiturate-induced coma or moderate hypothermia was not employed. Duration of ischemia was 2 hours. The patient was left with asymptomatic ipsilateral border-zone infarctions visible on CT scanning between the MCA and the anterior cerebral artery, and between the MCA and posterior cerebral artery vascular territories. The third patient with

FIG. 1. Cerebral angiograms in Case 11, a 66-year-old woman with a right cavernous sinus aneurysm and a right posterior communicating artery aneurysm. A and B: Preoperative cerebral angiograms, anteroposterior (A) and lateral (B) views. C and D: Follow-up angiograms, anteroposterior (C) and lateral (D) views, obtained 1 month later demonstrating successful clipping of both aneurysms.
TABLE 2
Clinical summary of 13 patients with intracavernous aneurysms receiving interventional radiological treatment*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Type of Aneurysm</th>
<th>Size†</th>
<th>Risk Group</th>
<th>Indications</th>
<th>Treatment</th>
<th>Outcome</th>
<th>Residual Deficit (new deficit)</th>
<th>Complications</th>
<th>Radiographic Follow-Up</th>
<th>Clinical Follow-Up (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9‡</td>
<td>23, M traumatic saccular</td>
<td>large</td>
<td>low</td>
<td></td>
<td>traumatic proptosis</td>
<td>proximal ICA occlusion</td>
<td>improved (dry eye)</td>
<td>none</td>
<td></td>
<td></td>
<td>1 mo</td>
</tr>
<tr>
<td>10</td>
<td>70, F spontaneous large saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>21 mos</td>
</tr>
<tr>
<td>12</td>
<td>15, M spontaneous giant saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>orbital pain</td>
<td>proximal ICA occlusion</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>2 mos</td>
</tr>
<tr>
<td>13</td>
<td>35, F spontaneous large saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion</td>
<td>improved</td>
<td>decreased vision</td>
<td>partial III</td>
<td>none</td>
<td>33 mos</td>
</tr>
<tr>
<td>15</td>
<td>30, F spontaneous giant saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis, orbital pain</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>40 mos</td>
</tr>
<tr>
<td>16‡</td>
<td>30, M spontaneous giant saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>1 mo</td>
</tr>
<tr>
<td>18</td>
<td>65, F spontaneous large saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>3 mos</td>
</tr>
<tr>
<td>6</td>
<td>62, M spontaneous large saccular</td>
<td>moderate</td>
<td></td>
<td></td>
<td>proptosis, orbital pain</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>10 mos</td>
</tr>
<tr>
<td>19</td>
<td>60, F spontaneous large saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>1 mo</td>
</tr>
<tr>
<td>21</td>
<td>34, M spontaneous giant saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>facial pain</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td>4 days</td>
</tr>
<tr>
<td>22</td>
<td>8, M traumatic saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>traumatic</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>small central hemisphere infarction</td>
<td>failed attempt; ICA dissection failure attempt</td>
<td>4 days</td>
</tr>
<tr>
<td>8</td>
<td>66, F spontaneous large saccular</td>
<td></td>
<td>low</td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>80, F spontaneous large saccular</td>
<td>moderate</td>
<td></td>
<td></td>
<td>proptosis</td>
<td>proximal ICA occlusion balloon trapping</td>
<td>asympt</td>
<td>none</td>
<td>femoral artery thrombosis</td>
<td>none</td>
<td></td>
</tr>
</tbody>
</table>

*Abbreviations: proptosis = progressive ophthalmoplegia; ICA = internal carotid artery; asympt = asymptomatic. Roman numerals denote cranial nerve palsy.
†Small: < 1 cm diameter; large: 1 to 2.5 cm diameter; giant: > 2.5 cm diameter.
‡Lost to follow-up review after 58 months.
§Died of postmortem-confirmed myocardial infarction; aneurysm thrombosed.

Fig. 2. Cerebral angiograms in Case 7, a 68-year-old woman with a right cavernous sinus aneurysm. A and B: Preoperative angiograms, anteroposterior (A) and lateral (B) views. C and D: Follow-up angiograms, anteroposterior (C) and lateral (D) views, obtained 3 months after surgical clipping and petrosal-to-supraclinoid internal carotid artery (ICA) saphenous-vein bypass grafting. Complete aneurysm isolation is revealed. The proximal end-to-end (arrowhead) and distal end-to-side (large arrow) anastomoses are evident, as is the clip placed on the supraclinoid ICA (small arrow) just proximal to the origin of the ophthalmic artery.
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infarction (Case 7) was in the moderate-risk group. During an attempt to clip the cavernous sinus aneurysm, the ICA was torn beyond repair, requiring temporary ICA occlusion. Since the saphenous vein had not been exposed ahead of time, 3½ hours of temporary occlusion was required to harvest the vein and perform a petro-sal-to-supraclinoïd ICA procedure. Induced hypertension, barbiturate-induced coma, or moderate hypothermia was not utilized. The patient awoke with a mild left hemiparesis that resolved in 3 months, leaving her with an asymptomatic small right frontal lobe infarction visible on CT scanning.

In five of the eight cases, the patient had persistent new cranial neuropathies at follow-up examination. Two had decreased ipsilateral vision or a reduced field. Four had partial third nerve paresis, Horner’s syndrome, a dry eye, or first division trigeminal hypesthesia was present in one patient each. Angiographic follow-up studies were available in all cases (mean follow-up period 4.1 months). In all cases, the aneurysm was completely excluded from the circulation. Both petro-sal-to-supraclinoïd ICA saphenous-vein bypass grafts were patent without evidence of stenosis, pseudoaneurysm formation, or accelerated atherosclerosis.

Interventional Radiology

A clinical summary listing the aneurysm characteristics, the treatment chosen, clinical outcome, and treatment complications for the 13 patients treated with interventional radiological techniques is presented in Table 2. The mean patient age was 44 ± 23 years. Balloon occlusion of the ICA proximal to the cavernous sinus aneurysm was performed in five cases, balloon trapping of the cavernous ICA in one case, and intra-aneurysm embolization with preservation of the ipsilateral ICA in five cases (Fig. 3). There was no procedure-related mortality. At follow-up examination, four patients were asymptomatic, five had improved symptomatically, two were clinically unchanged, and none had worsened.

There were two procedure-related infarctions apparent on CT scanning. Both were embolic and occurred during intra-aneurysm embolization with preservation of the ipsilateral ICA lumen. In Case 6, the aneurysm was partially thrombosed and inflation of the second intra-aneurysmal balloon dislodged a piece of thrombus, leading to angiographically confirmed occlusion of the ipsilateral angular artery. The patient developed a mild contralateral hemiparesis that resolved in 3 days and was left with subtle word-finding difficulties and a small hypodense area in the left parietal region on follow-up CT scans. In Case 22, a balloon was lost at the time of detachment, leading to angiographically confirmed occlusion of an anterior MCA branch. The patient developed a left pronator drift that resolved within 24 hours, and had an asymptomatic hypodense area in the right centrum semiovale on CT scans. Only two patients demonstrated persistent new cranial neuropathies at follow-up examination. One had a partial right sixth nerve paresis, and one complained of an ipsilateral dry eye. There were two failed embolization attempts due to an inability to navigate tortuous arteries. Other technical complications included hemodynamically insignificant ICA dissections in two cases and a femoral artery thrombosis requiring thrombectomy in one case.

Radiographic follow-up studies were available in all cases (mean follow-up period 10.2 months). Complete thrombosis of the aneurysm was demonstrated for all five cavernous sinus aneurysms treated by proximal ICA balloon occlusion and in the single case treated with balloon trapping. Complete thrombosis of the aneurysm with preservation of the ipsilateral ICA lumen was present immediately in two cases and after 10 days.

Fig. 3. Cerebral angiograms, lateral views, in Case 18, a 65-year-old woman with a right cavernous sinus aneurysm. A: Pre-embolization angiogram. B: Follow-up angiogram obtained 3 days after detachable balloon embolization of the aneurysm demonstrating complete aneurysm occlusion and preservation of the ipsilateral internal carotid artery lumen.
months in one case treated by intra-aneurysm embolization. In two of the five cases, less than 10% of the aneurysm lumen still filled with contrast medium on follow-up angiography; we continue to monitor these patients.

Discussion

The advent of even more sensitive diagnostic imaging techniques has led to the discovery of more intracavernous carotid artery aneurysms than ever before. Yet the mere presence of a cavernous sinus aneurysm shown on diagnostic imaging does not justify submitting that patient to the risk of morbidity and mortality associated with an attempt to treat the lesion. Up to 34% of intracavernous carotid artery aneurysms are asymptomatic at diagnosis.23 Since the mortality rate from untreated cavernous sinus aneurysms is low,28 treatment in this group should be reserved for patients whose aneurysm extends into the subarachnoid space or arises from the anterior genu of the cavernous ICA, since both of these circumstances are associated with SAH.23 Even the presence of one or more cranial neuropathies does not justify intervention since up to 40% of patients with cranial neuropathies from cavernous sinus aneurysms will improve spontaneously over time without treatment.28 Treatment in symptomatic patients should be reserved for those with proven progressive ophthalmoplegia or loss of vision, for those with severe ipsilateral facial or orbital pain, for those who demonstrate aneurysm enlargement on CT scanning, and for those with epistaxis or SAH.23

It is clear from Tables 1 and 2 that the surgically and radiographically treated patient groups are not similar in composition. Patients in the surgical group tended to fall into a higher risk category, while patients in the radiological treatment group tended to have larger cavernous sinus aneurysms. This disparity does not allow a fair comparison of results and complications between patient populations. Fortunately, other studies using either surgical13-16 or interventional radiological techniques8,23,39,51 exclusively have reported their success and morbidity and mortality rates, allowing comparisons to be made. Our results with both techniques compare favorably with those reported recently in the literature.

Pretreatment Evaluation

Although cranial nerve dysfunction after treatment can be debilitating to patients, the major cause of morbidity and mortality associated with treatment of cavernous sinus lesions is ipsilateral hemispheric ischemia related to management of the ICA. In our experience, treatment risk depends more on the adequacy of collateral circulation than on the size of the cavernous sinus aneurysm. Even if a cavernous sinus aneurysm is approached with a treatment designed to preserve the ICA, temporary occlusion may be necessary to achieve the desired result, and unforeseen technical difficulties could require permanent ICA sacrifice. Pretreatment evaluation of the risk of temporary or permanent ICA occlusion thus becomes the most important step in the therapeutic decision-making process for intracavernous carotid artery aneurysms.

The clinical balloon test occlusion is a modern version of the Matas test.4 Others have used a clinical balloon test occlusion alone or in concert with electroencephalography,2 compressed spectral array,32 or SSEP monitoring. Each of these balloon test occlusion variations is roughly similar, in that they all identify patients whose CBF drops below 18 to 20 ml/100 gm/min with carotid occlusion.2,23,25,26,48 The addition of the Xe/CT CBF study to the evaluation helps identify a second group of patients with ICA CBF's less than 30 ml/100 gm/min who tolerate temporary ICA occlusion but who have a low CBF reserve and are at increased risk for stroke should their ICA be permanently occluded.10,15 By separating moderate-risk patients from the low-risk group, we hope to eliminate the incidence of delayed ischemic deficits that have been reported with ICA occlusion despite a negative Matas test,6,31,34,37,50 and have eliminated the need for gradual cervical carotid artery occlusion in low-risk patients. Compared with gradual cervical ICA occlusion, balloon occlusion of the ICA has the advantage of limiting the length of the resultant carotid artery stump, thus reducing the risk of stump embolization. Balloon ICA occlusion is almost always performed under local anesthesia, which is a significant advantage given that the median age of patients diagnosed with cavernous sinus aneurysms is 61 years, and 43% are hypertensive.25

Long-Term Sequelae of Carotid Artery Sacrifice

Although some authors argue that treatment for cavernous sinus aneurysms should always preserve the ipsilateral ICA lumen,13 we suggest that the appropriateness of ICA sacrifice should be based on clinical outcome and the documented risks of carotid artery occlusion, and not on aesthetic grounds. One significant documented risk concerns the presence of a berry aneurysm contralateral to the cavernous sinus aneurysm, which has been shown to grow and/or rupture following ipsilateral ICA sacrifice.4,5,6,37 We consider the presence of a contralateral berry aneurysm to be a contraindication for ICA sacrifice. This contraindication is particularly relevant for intracavernous carotid artery aneurysms since 21% of them are bilateral.27

Some evidence suggests that patients may be at increased risk later in life for ipsilateral ischemic deficits after ICA sacrifice.2,3,20,21,33,53 Although this risk does not appear to be very large, it does make us cautious about ICA sacrifice in very young patients.

The idea that ICA sacrifice may lead to an increased risk of developing contralateral de novo aneurysms is based on a documented increased risk of aneurysm formation in patients with congenital aplasia or hypoplasia of one carotid artery.18,45 as well as on a few documented cases of contralateral de novo aneurysm formation after therapeutic carotid occlusion.14 At this
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**Low-Risk Group**

Our experience in over 300 balloon test occlusion-Xe/CT CBF studies shows that approximately 75% of all patients fall into the low-risk category. For older patients in this group, balloon occlusion of the ipsilateral ICA proximal to the aneurysm is currently our procedure of choice since it carries the lowest morbidity and mortality rates and because of its excellent clinical results. Embolization of the aneurysm with preservation of the ICA is technically more difficult, but excellent results have been achieved with it. This technique, however, has a slightly higher risk of embolic infarction and we are wary of using it for partially thrombosed aneurysms. Care must be taken to fill the entire aneurysm and not just the aneurysm neck, since the balloon can later migrate into the aneurysm leading to aneurysm rupture. At least three case reports suggest that if any part of the aneurysm still fills with contrast medium on angiography after embolization, then the aneurysm is not protected from rupture. Even if the aneurysm does not fill with contrast material, the aneurysm may not be protected from rupture until at least 6 months after treatment (G Hieshima, personal communication, 1990).

Even in the best of hands, direct surgical approaches to the cavernous sinus carry a higher rate of morbidity and mortality than balloon occlusion techniques. The increased incidence of ischemic complications associated with surgery may represent selection bias since most interventional radiologists perform at least a clinical balloon test occlusion and exclude patients who fail, while most surgeons who have published their results do not. The increased incidence of cranial neuropathy associated with surgery no doubt reflects the need to enter the cavernous sinus with that surgical approach. In this category of patients, direct surgical approaches should be reserved for younger patients, for situations where interventional radiology is not available, and for patients with contralateral berry aneurysms.

**TABLE 3**

**Treatment options based on patient risk group**

<table>
<thead>
<tr>
<th>Order</th>
<th>Options</th>
<th>Order</th>
<th>Options</th>
<th>Order</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>reconsider treatment</td>
<td>1</td>
<td>EC-IC bypass &amp; repeat BTO</td>
<td>1</td>
<td>balloon occlusion of proximal ICA</td>
</tr>
<tr>
<td>2</td>
<td>EC-IC bypass &amp; repeat BTO</td>
<td>2</td>
<td>clip aneurys</td>
<td>2</td>
<td>aneurysm embolization with ICA preservation</td>
</tr>
<tr>
<td>3</td>
<td>clip aneurys</td>
<td>3</td>
<td>aneurysm embolization with ICA preservation</td>
<td>3</td>
<td>clip aneurys</td>
</tr>
<tr>
<td>4</td>
<td>aneurysm embolization with ICA preservation</td>
<td>4</td>
<td>cavernous ICA trapping with P-S</td>
<td>4</td>
<td>trap aneurys ± P-S</td>
</tr>
<tr>
<td>5</td>
<td>EC-IC bypass followed by cavernous ICA trapping with P-S</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>cavernous ICA trapping with P-S using barbiturate coma &amp; hypothermia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*EC-IC = extracranial-intracranial; BTO = balloon test occlusion; ICA = intracranial carotid artery; P-S = petrosal-to-supraclinoid ICA sphenous-vein bypass. For determination of risk group see protocol depicted in Fig. 4.*

**J. Neurosurg. / Volume 75 / October, 1991**
The cavernous sinus aneurysms most amenable to clipping are those arising from the anterior one-third of the intracavernous ICA, although aneurysm clipping or aneurysmorrhaphy has been achieved at most sites within the cavernous sinus. For more posteriorly placed aneurysms and aneurysms without a definable neck, a trapping procedure is performed. If the patient is young or has a contralateral aneurysm, we advocate performing a petrosal-to-supraclinoid ICA saphenous-vein bypass. This type of bypass is preferred over a superficial temporal artery-to-MCA (STA-MCA) bypass because it provides antegrade flow equal to that in the original ICA, can be performed through the same exposure, takes only slightly more time to perform, and does not require time to mature.

**High-Risk Group**

Approximately 10% of patients do not tolerate the clinical balloon test occlusion. These patients are at maximum risk for stroke even with temporary ICA occlusion. Fox, et al., reported three patients who failed a clinical balloon test occlusion but tolerated balloon test occlusion after elective STA-MCA bypass and went on to have a therapeutic ICA occlusion without stroke. However, these patients have very poor collateral circulation, and the flow from an STA-MCA bypass may not always be adequate to prevent a stroke.

If the clinical situation will not allow elective STA-MCA bypass with delay until a balloon test occlusion can be tolerated, then a treatment must be chosen that has a chance of preserving ICA patency. Balloon embolization of the aneurysm is one such treatment, but this provides little alternative should technical difficulties arise during the procedure. Another option is attempting to clip the aneurysm using moderate hypothermia, barbiturate-induced coma, and induced hypertension as cerebral protection during any periods of temporary occlusion. Should a trapping procedure be necessary (such as for traumatic cavernous sinus aneurysms with epistaxis), then an STA-MCA bypass at the start of the procedure or induced hypertension, barbiturate coma, and moderate hypothermia may allow for the temporary ICA occlusion necessary to create a more robust petrosal-to-supraclinoid ICA saphenous-vein bypass, although the efficacy of these measures remains to be proven. The two petrosal-to-supraclinoid ICA saphenous vein bypass procedures in this series were performed early in our experience with this technique. Further experience in patients with cavernous sinus tumors has resulted routinely in ICA temporary occlusion times of less than 90 minutes.

**Moderate-Risk Group**

Approximately 15% of patients fall into the moderate-risk category. Therapeutic options for these patients include all the options discussed for those in the high-risk group. Fortunately, patients in this group are at low risk for deficit with temporary ICA occlusion, so drastic measures are probably not necessary for cerebral protection during temporary occlusion, although they probably increase the margin of safety. However, these patients have low CBF reserves and probably should not undergo permanent ICA occlusion without a revascularization procedure.

**Traumatic Cavernous Sinus Aneurysms**

Traumatic intracavernous carotid artery aneurysms fall into a special category since these are really pseudoaneurysms without a true arterial wall and often present with life-threatening epistaxis. Once epistaxis has occurred, proximal and distal trapping of the aneurysm using either detachable balloon techniques or direct surgical techniques are the treatment of choice because of the high risk of recurrent and potentially fatal epistaxis from collateral circulation if only a proximal ICA occlusion is performed.

**Conclusions**

The major risks of morbidity and mortality associated with intracavernous carotid artery aneurysm treatment arise from ipsilateral hemispheric ischemia related to the management of the ipsilateral ICA. Pretreatment evaluation of the risk of temporary or permanent ICA occlusion thus becomes the cornerstone of the therapeutic decision-making process. Our treatment protocol is based on our clinical experience treating cavernous sinus aneurysms with surgery and interventional radiological techniques, as well as the results of others reported in the literature. The protocol relies on a clinical balloon test occlusion-Xe/CT CBF study to divide patients into high-, moderate-, and low-risk groups. Options for treatment of patients in each group, as well as the rationale for our current prioritization of options, are critically discussed.

The therapy of intracavernous carotid artery aneurysms will continue to improve, new techniques will no doubt be developed, and current methods will be upgraded in terms of safety and efficacy. Our protocol has enough inherent flexibility to allow for the addition of new techniques and the reorganization of treatment option priorities as this evolution continues.

**Acknowledgment**

The authors thank Joan Russo for her assistance with preparation of the manuscript.

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Manuscript received October 3, 1990.
Accepted in final form February 25, 1991.
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