Carotid thromboendarterectomy: a reappraisal

Criteria for patient selection

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Thromboendarterectomy performed in 35 patients with symptoms distal and ipsilateral to an occluded internal carotid artery resulted in patency in 19 cases (53%). Two factors that influence successful operation are early intervention following occlusion and good collateral circulation. In only 12 patients (34%) could the interval from occlusion to surgery be confidently determined. Four of these vessels, occluded for up to 7 days (100%), and five of eight vessels (63%), occluded for up to 4 weeks, were reopened. In the remaining patients, where the duration of occlusion was indefinite, greater reliance was placed on the evaluation and grading of angiographic collateral supply distal to the occlusion. Patients with Grade 1 to 3 collateral supply should not be explored unless occlusion occurred very recently. Patients with Grades 4 and 5 collateral supply are considered for carotid exploration regardless of the duration of the occlusion, as an alternative to other methods of revascularization.

KEY WORDS • thromboendarterectomy • carotid occlusion • angiography • collateral circulation grades

THE majority of internal carotid artery (ICA) occlusions are superimposed on a stenotic atheromatous plaque at the extracranial carotid bifurcation. Trauma, inflammation, dissection, coagulopathies, fibromuscular hyperplasia, and other stenotic lesions more distal in the vessel may also initiate thrombosis. Symptomatology spans a broad spectrum, ranging from a complete lack of symptoms to a sudden catastrophic fatal stroke. The recognized cessation of repeated neurological events, coincident with the occlusion of a previously stenotic vessel, has led some to consider occlusion of the ICA a relatively benign entity. Nevertheless, delayed postocclusion ischemia is a known possible sequela to ICA occlusion. The natural history of this problem is not benign, although it is apparently less ominous than that of repeated transient ischemic attacks (TIA’s) from a stenotic plaque. Repeated ischemic events, distal to an ICA occlusion, have invariably been ascribed to emboli and hemodynamic factors.

Controversy continues regarding surgical intervention in cases of ICA occlusion. On the one hand, reported restoration of patency in occluded carotid arteries has been disappointing, except where surgery was undertaken within hours of the occlusion. In addition, only 50% of vessels initially reopened apparently remained patent when reassessed later. These factors, along with the morbidity ascribed to the surgical technique of thromboendarterectomy, have led a number of surgeons to consider alternative means of revascularization of hemispheres that were ischemic due to ICA occlusion. On the other hand, there are several reports of successful reconstitution of flow in chronically occluded ICA’s, accompanied by resolution of symptoms after external carotid endarterectomy and modification of an ICA “stump,” and these studies support the view that careful evaluation of these patients will reveal a significant number in whom surgery should first be directed to the occluded vessel itself, and its point of origin at the carotid bifurcation in the neck.

Clinical Material

In a group of 55 patients subjected to various revascularization procedures for ischemic events in association with an occluded ICA, 35 patients, whose
events were confined to the vascular territory distal and ipsilateral to the carotid occlusion, were subjected to 36 carotid explorations. The follow-up period extended up to 8 years, with an average of 3 1/2 years. The clinical and angiographic characteristics of these patients are outlined in Table 1. In only 12 (34%) of the 35 patients could the interval from occlusion to surgery be confidently determined. In 28 cases (80%), the onset of symptoms preceded surgery by more than 2 weeks; in 17 (49%), the most recent symptom occurred within 1 week of surgery.

In all cases, careful, detailed angiographic visualization of the extracranial and intracranial portions of the entire anterior and posterior circulation was performed to confirm complete occlusion and to fully visualize available collateral circulation. This determination necessitated a careful review of both the early and late films in the angiographic sequence, augmented by subtraction films. Special techniques of high-volume timed injections were not used. All patients were anticoagulated before and during surgery, using heparin during the actual thromboendarterectomy.

Absolute contraindications to thromboendarterectomy included drowsiness, major neurological deficit incompatible with a return to self-care and independence, and the presence of tandem lesions distal to the ICA occlusion. We did not hesitate to perform emergency thromboendarterectomy in patients with a progressing stroke, or shortly after any major neurological event as long as there was no drowsiness and the deficit was compatible with self-care and independence. Anticoagulation in the form of antiplatelet therapy was continued for at least 1 month after the operation.

**Surgical Technique**

Normotension, normovolemia, and normocapnia were maintained throughout the operation. Where thromboendarterectomy was chosen to improve and restore perfusion to the bed of the ICA, every effort was made to preserve collateral circulation through the external carotid artery. A standard arteriotomy through the bifurcation that requires temporary occlusion of the common and external carotid arteries must be avoided until retrograde flow is re-established. Accordingly, high exposure of the ICA well above the bifurcation was considered essential, even to the point of transecting the posterior belly of the digastic muscle in some instances. A high arteriotomy was then placed in the ICA well above the occluding plaque at the bifurcation, avoiding any need to compromise collateral flow while attempting to restore retrograde flow down the artery. Often very little instrumentation was required to restore retrograde flow, but a No. 3 or 4 Fogarty catheter could be passed without difficulty in most instances well into the artery in the internal carotid canal. If good retrograde flow was established, as opposed to a mere trickle of blood, then the distal ICA was immediately occluded along with the common and external carotid arteries, and the arteriotomy was quickly extended down through the occluding plaque at the bifurcation into the common carotid artery. An intraluminal bypass shunt was then quickly inserted from the common into the internal carotid artery, restoring perfusion of the hemisphere while the critical collateral circulation from the external carotid artery was now briefly obliterated. The occluding plaque at the carotid bifurcation, which invariably also extends into the external carotid origin, was then removed as in any standard carotid endarterectomy. If, on the other hand, satisfactory retrograde flow could not be re-established, no attempt was made to restore antegrade flow, and the arteriotomy in the ICA was simply closed. A decision was then made according to the preoperative angiographic evaluation as to whether a separate arteriotomy at the bifurcation was required to perform an endarterectomy of the external carotid artery for a stenosis or ulcer.

**Surgical Results**

Since one of our patients with bilateral symptoms had bilateral ICA occlusions, both vessels were explored. Accordingly, 36 carotid arteries were explored in the present series. Each vessel was found to be occluded at the time of exploration, and patency was restored in 19 (53%). Symptoms ceased in all cases with successful restoration of flow. Negative explorations did not result in any worsening of any patient's condition.
FIG. 1. Five grades of angiographic collateral supply. See Table 2 for a description.

TABLE 2
Grading of angiographic collateral supply*

<table>
<thead>
<tr>
<th>Angiographic Grade</th>
<th>No. of Cases</th>
<th>Angiographic Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>nonvisualization of entire intracranial ICA</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>visualization of ICA proximal to anterior choroidal &amp; posterior communicating arteries, distal to ophthalmic artery</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>visualization of ICA proximal to ophthalmic artery, distal to meningohypophyseal trunk</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>visualization of cavernous ICA to the point of superimposition of the ICA &amp; floor of the sella turcica</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>visualization of ICA into the carotid canal, but not beyond base of skull.</td>
</tr>
</tbody>
</table>

*ICA = internal carotid artery.

Careful preoperative clinical evaluation of these patients revealed that, while the onset of occlusion could be considered to coincide with a sudden major neurological event superimposed on a previous asymptomatic history or a history of TIA’s, it could seldom be accurately determined in patients presenting with minor neurological events (Table 1). Angiography demonstrated various patterns of collateral circulation that could be classified into five grades of angiographic collateral supply (Table 2 and Fig. 1). Representative examples of the two commonest patterns, Grades 3 and 5, are seen in Fig. 2. We excluded from this group of patients cases in which a thread of dye was visualized in the cervical extracranial portion of the ICA beyond its origin from the carotid bifurcation. It was our contention that this picture more likely represents a trickle of antegrade flow through a very tight stenosis at the internal carotid origin, as opposed to retrograde flow from collaterals into the cavernous portion of the ICA. Hence, those patients were considered as having incomplete ICA occlusions, and are distinct from the present group. Note the frequent occurrence of Grade 4 and 5 patterns (14 patients), indicating collateral filling of the entire cavernous portion of the ICA. This group is reportedly amenable to surgical reconstruction of flow, even in a setting of chronic occlusion.4,40

Among the 12 patients in whom the time of occlusion could be confidently determined, patency was successfully re-established in all four vessels (100%) occluded for less than 1 week, including one with only a Grade 2 collateral pattern (Table 3). Patency was re-established in five of the remaining eight vessels (63%) occluded for up to 28 days, including two with only a Grade 3 pattern. Among the remaining 23 cases in which the time of occlusion could not be confidently determined, no correlation was observed between success or failure in establishing patency and interval from onset of symptoms, or the presence or absence of a “stump.”

Although there was diminished likelihood of reopening a vessel if the most recent symptom preceded surgery by more than 1 week, the predominance of TIA’s as the presenting symptom in some of these cases did not favor patency, as suggested by Lougheed, et al.44 Abundant collateral circulation beyond the occlusion favored successful thromboendarterectomy even in chronically occluded vessels14,24,32,45,48 (Table 4). In the 15 patients with a Grade 4 and 5 pattern, 13 vessels were reopened regardless of the duration of the occlusion; one of these patients was an elderly woman whose symptomatic carotid occlusion had been angiographically documented 3 years before successful thromboendarterectomy. The two Grade 4 vessels not reopened had been occluded for 3 years in one instance and probably up to 7 months in the other. None of the Grade 1 vessels was reopened, even when thromboendarterectomy was attempted immediately after the onset of symptoms. Similarly, only six of 18 Grade 2 and Grade 3 vessels were reopened. Five of these six cases underwent surgery within 7 days of presumed occlusion. Thus, with the exception of Grade 1 patients, recent occlusions of up to 7 days could be reopened regardless of angiographic grade. Chronic occlusions could be reopened if angiographic collateral supply extended back to the carotid canal.

Although the majority of the vessels explored contained thrombus (26 vessels) in various stages of organization and adherence to the vessel wall beyond the occluding plaque at the origin, the lumina in six vessels were seemingly empty beyond the occluding...
plaque. In four of these cases, brisk retrograde flow was immediately encountered at arteriotomy without any sign of antegrade flow, including the vessel re-opened after 3 years of documented occlusion; in the other two cases, there was a further obstruction to retrograde flow distally in the vessel. In addition, there were four instances in which the chronically occluded vessel had been converted into a small fibrous band, with no recognizable lumen and no hope of restoring flow. There was no correlation between the findings at surgery and the angiographic collateral supply, except that three of the four cases with a seemingly empty lumen and immediate retrograde flow had demonstrated a Grade 5 pattern of angiographic collateral supply.

Symptoms in the territory of the occluded vessels ceased following successful thromboendarterectomy in each instance, but continued within 7 days to 5 years following unsuccessful carotid exploration in nine of 16 patients who required subsequent re-vascularization procedures. In five patients, symptoms were subsequently recorded in the territory of other vessels.

Postoperative angiography was performed in 22 of 35 patients. In cases of successful thromboendarterectomy, it was only performed if complications or further symptoms occurred to suggest distal embolization. In four of these cases, brisk retrograde flow was immediately encountered at arteriotomy without any sign of antegrade flow, including the vessel re-opened after 3 years of documented occlusion; in the other two cases, there was a further obstruction to retrograde flow distally in the vessel. In addition, there were four instances in which the chronically occluded vessel had been converted into a small fibrous band, with no recognizable lumen and no hope of restoring flow. There was no correlation between the findings at surgery and the angiographic collateral supply, except that three of the four cases with a seemingly empty lumen and immediate retrograde flow had demonstrated a Grade 5 pattern of angiographic collateral supply.

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**TABLE 3**

<table>
<thead>
<tr>
<th>Period of Occlusion</th>
<th>Total Cases</th>
<th>ICA Reopened No.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td>4</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>1-4 wks</td>
<td>8</td>
<td>5</td>
<td>63</td>
</tr>
<tr>
<td>indefinite</td>
<td>24</td>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td>total</td>
<td>36</td>
<td>19</td>
<td>53</td>
</tr>
</tbody>
</table>

*ICA = internal carotid artery.

**TABLE 4**

<table>
<thead>
<tr>
<th>Angiographic Grade</th>
<th>Total Cases</th>
<th>ICA Reopened No.</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2, 3</td>
<td>18</td>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>4, 5</td>
<td>15</td>
<td>13</td>
<td>87</td>
</tr>
</tbody>
</table>

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bolus or reocclusion (three cases), or to assess collateral supply from the reopened vessel if further surgery was contemplated to the other side (four cases). Fifteen of 16 vessels not reopened were re-examined from within 4 days to 11 months of surgery to assess the results of further revascularization, as in the case of external carotid endarterectomies (five cases), opposite carotid endarterectomies (two cases), and extra- to intracranial anastomosis (nine cases).

There were no operative deaths; however, late follow-up review revealed four deaths. Two patients died as a result of myocardial ischemic disease. One patient died from a spontaneous intracerebral hemorrhage in the hemisphere opposite to the reopened ICA. One patient died following a basilar artery thrombosis 5 years postoperatively.

Four major preventable complications were encountered. Two patients suffered acute reocclusion accompanied by major neurological deficit within hours of successful thromboendarterectomy. Each patient suffered acute hypotension in the recovery room, attributed to excess sedation. This complication was superimposed on a previously unrecognized stenosis at the common carotid origin in one of these two patients. Profound hypotension and hypertension are recognized sequelae following surgery at the carotid bifurcation, and require prompt treatment to avoid reocclusion or spontaneous intracerebral hemorrhage. Minor trauma to the sinus and vagus nerves during dissection may contribute to these deleterious responses and should be avoided with careful technique. One patient awoke hemiplegic and aphasic from an embolus to the middle cerebral artery after successful thromboendarterectomy. Review of the initial angiograms confirmed evidence of a tandem lesion in the hemisphere opposite to the reopened ICA. One patient died from a spontaneous intracerebral hemorrhage in the hemisphere opposite to the reopened ICA. One patient died following a basilar artery thrombosis 5 years postoperatively.

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lumen; however, in four other instances, the vessel distal to the occluding plaque contained no thrombus at all but yielded immediate brisk retrograde flow, yet no antegrade flow. Angiographically, collateral flow was observed only as far back as the base of the skull, and, at surgery, the vessel was palpably soft and seemingly empty until the arteriotomy was made and the retrograde flow promptly appeared. Hence, there were no angiographic clues to predict this fortunate finding at surgery. Possibly the retrograde collateral flow into the distal ICA, although sufficient to fill back to the base of the skull where collapse of the artery is prevented by adhesions between its adventitia and the periosteum of the carotid canal, cannot overcome the effects of atmospheric pressure on the cervical portion of the ICA where the artery behaved much like a collapsible vein.

It is not clear whether the proposed classification into five angiographic grades of collateral supply has any advantages over a more simplified classification that combines Grades 2 and 3 as well as Grades 4 and 5. The present limited experience has suggested that all Grade 5 vessels (eight) could be reopened regardless of the duration of occlusion; while only four of six Grade 4 vessels were reopened, and hence the differentiation. Only the evaluation of a much larger number of cases will ultimately determine whether the classification into five grades maintains any value over a simpler grouping into three grades.

Although complications have been described from instrumentation of the distal ICA, these can be minimized by carrying out a high arteriotomy in the ICA, which also avoids the need at the time to compromise existing collateral flow through the external carotid artery. The use of anticoagulant drugs before and during surgery reportedly enhances the likelihood of restoring patency, but does dictate judicious hemostasis to avoid postoperative hematomas. If carefully performed, carotid explorations that prove unsuccessful in the attempt to restore ICA patency are unlikely to result in any deterioration of the patient's condition, if the collateral flow through the external carotid artery is not disturbed during the initial ICA exploration. The exploration does provide the option of performing a concurrent endarterectomy of the external carotid artery origin to improve available collateral circulation and to remove an ulcer crater or ICA "stump" that may serve as a possible source of emboli.

The early reocclusion observed in two cases included the common and external carotid as well as the ICA, and resulted in significant neurological deficit, to the point that immediate re-exploration was considered inappropriate for the same reasons that thromboendarterectomy is contraindicated in the setting of severe neurological deficit. However, the remaining patients whose vessels were reopened are still asymptomatic, and accordingly, late follow-up angiography or other indirect evaluations were not performed in 11 of these patients. It is possible that some of these vessels have reoccluded. Perhaps the extensive removal of the offending plaque at the carotid bifurcation, including particularly its extension into the external carotid artery, provides enhanced collateral flow in cases of reocclusion of the ICA. None of the patients whose vessels could not be reopened were worse as a result of the carotid exploration, and in five of these 17 cases, symptoms ceased following the concurrent external carotid endarterectomy. Hence, it would appear that exploration of the occluded ICA is a safe procedure if clinical and angiographic guidelines are followed, and may in fact be preferred over other primary revascularization procedures.

Conclusions

The two major determinant factors that may influence the choice of carotid exploration over other recognized revascularization procedures include the period of occlusion from the time of surgery, when known, and the degree of collateral supply beyond the occlusion. Early intervention within 1 week of occlusion, using the technique described, will almost invariably lead to a successful thromboendarterectomy, regardless of the extent of collateral supply distal to the occlusion. On the other hand, since the onset of occlusion is not known in the majority of patients, greater dependence is required on the evaluation of collateral supply. Cases of Grade 4 and 5 angiographic collateral pattern should be explored regardless of the period of occlusion, but cases of Grade 1 to 3 angiographic pattern should not be subjected to carotid exploration unless occlusion is known to be very recent. In those instances, alternative means of revascularization are preferred as primary surgical procedures over carotid exploration.

References

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