Technical Aspects of Carotid Endarterectomy with Hemashield Patch Graft

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Abstract

In this review I describe my method of carotid endarterectomy with synthetic patch angioplasty. The use of Hemashield patch angioplasty is relatively new in my practice, and since I have adopted it I feel it has reduced or eliminated early restenosis and acute postoperative occlusion. The technique is simple and straightforward, and does not require any special preparation of the patch material. The patch is stronger and safer than saphenous vein. The other steps of the endarterectomy are unchanged, and the same suture can be used for patch placement. I also describe here a new commercial shunt which I have developed and which I feel is an improvement over the shunts I previously used. I place an indwelling shunt selectively, if electroencephalography criteria indicate that a shunt is needed. In my series this occurs in 15% of cases, increasing to 25% in patients with contralateral carotid artery occlusion. The overall stroke rate in my carotid artery series is 1.8% at present.

Key words: carotid artery surgery, carotid endarterectomy, Hemashield patch, stroke

Introduction

Carotid endarterectomy, first performed in 1954,\textsuperscript{6} is being increasingly performed by neurosurgeons worldwide now that the benefits of carotid artery reconstruction over medical therapy alone have been validated by cooperative trial data. We now have proven efficacy for carotid endarterectomy in symptomatic patients with lesions of ≥70% linear stenosis\textsuperscript{19,20} and, according to those who believe in the Asymptomatic Carotid Atherosclerosis Study (ACAS) (myself included),\textsuperscript{1,18} in asymptomatic patients with ≥60% stenosis as well. In this review I hope to describe what I consider to be basic, careful, and safe technique for carotid artery reconstruction, as well as outlining the scientific foundation for the various operative decisions facing the cerebrovascular surgeon. There is more than one way to do any given operation, and all variations cannot be demonstrated here. A more complete discussion of indications, special considerations, and nuances of surgical technique can be found in more detailed technical writings.\textsuperscript{14,16,17}

One of the most recent technical advances in carotid artery repair is the use of the operative microscope. Several authors have reported excellent surgical results with microscopic technique, and certainly neurosurgeons have great expertise in other areas of microsurgery.\textsuperscript{10,23} I have personally tried both conventional loupe-magnified and formal microscopic repair of the internal carotid artery (ICA) at various stages of my career. There is no doubt that the microscope increases lighting and allows for superior visualization of the distal ICA endarterectomy for primary anastomosis. At present, however, I use the 3.5 \times\ loupe-magnified technique, with placement of a Hemashield patch graft in every case. Whereas microscopic endarterectomy is certainly elegant, yielding a repair that is nearly invisible to the naked eye, it did not seem to impact my incidence of restenosis or acute occlusion. Primary patch graft placement, in my experience, has essentially eliminated these problems in the 2 years that I have employed it. For the individual surgeon who chooses primary anastomosis instead of patch angioplasty I would strongly endorse microscopic carotid artery technique.

Technique Choices

I. Anesthetic technique

Proponents of local anesthesia stress the advantages of patient response to questioning as a superior monitoring technique in assessing the need...
for shunt placement, and in reducing postoperative morbidity and shortening length of stay. Monitoring under local anesthesia consists of direct patient questioning and performance of a simple task with the opposite hand during cross-clamping. The risk of patient disorientation from ischemia with subsequent movement and contamination of the operative field can be minimized by careful monitoring and sedation by the anesthetist. We have recently analyzed our own institutional data, comparing the incidence of electroencephalography (EEG) changes and the need for shunting between two surgeons: a vascular surgeon who uses only local anesthesia with EEG, and myself, using general anesthesia with EEG.26 The incidence of EEG changes and shunt placement was less in this series with local anesthesia. There was no difference, however, in stroke rate, complications, outcome, or length of stay. The awake technique involves either direct injection of cervical tissues or a regional cervical plexus block placed by the anesthesiologist. Either technique is satisfactory in experienced hands. Surgeons who use the cervical block report that supplementary local anesthetic injection is often needed. A complete description of the technique and its advantages can be found in Harbaugh's recent article.12

General anesthesia remains my technique of choice for carotid artery surgery in almost all cases. The acceptance of local anesthesia is increasing, however, particularly with new emphasis in the U.S.A. on reducing length of stay. Some have suggested that carotid artery surgery be performed essentially as an outpatient procedure4 although I have strong reservations about this, particularly in patients with associated risk factors. Patients on my cerebrovascular service are admitted on the day of surgery, spend a single postoperative night in the surgical intensive care unit, and are discharged on the 2nd postoperative day. I have on several occasions performed successful carotid endarterectomies under local anesthesia when the patients had pulmonary problems so severe that postoperative ventilator dependence was a risk. I feel that carotid surgeons should be familiar with the local/regional technique and be prepared to use it at least in circumstances where general anesthesia may be contraindicated (these are rare occasions in my practice).

II. Monitoring techniques

Intraoperative monitoring during carotid artery cross-clamping is performed to assess the need for placement of an indwelling carotid artery shunt. Monitoring techniques fall into two broad categories: 1) tests of vascular integrity, such as stump pressure measurements, xenon regional cerebral blood flow studies, transcranial Doppler, and to a lesser extent intraoperative ocular plethysmography, Doppler/duplex scanning, and angiography; and 2) tests of cerebral function, such as EEG, EEG derivatives, and/or somatosensory evoked potential monitoring. The suitability of near-infrared spectroscopy for carotid artery surgery monitoring is unclear at present.24 The choice of technique will depend on the surgeon's preference and the resources available at the institution. In my practice we use full channel EEG interpreted by a neurologist on-line. I also perform audible Doppler examination of the carotid tree following the arterial repair.

III. Intraoperative shunting

The necessity for indwelling arterial shunt during carotid endarterectomy is one of the most widely debated and long-standing controversies in neurovascular surgery. Carotid surgeons generally align themselves into three groups: those who use shunts in every case, those who employ shunting when indicated by some form of intraoperative monitoring (see above), and those who never shunt no matter what the clinical or monitoring situation. Although I was trained in universal shunting, I feel this is excessive, and I perform monitoring-dependent shunting based on EEG criteria. In my experience we shunt about 15% of carotid endarterectomies; this increases to about 25% if the contralateral carotid artery is occluded. When a shunt is placed and flow is re-established the monitoring should return to baseline, and if this does not occur the shunt must be evaluated for possible thrombosis or misplacement. We auscultate the shunt with a Doppler probe which works well to confirm patency and shunt flow. I have had only one case where a demonstrably patent shunt did not restore the EEG; the shunt was removed and replaced twice in an unsuccessful attempt to improve the EEG; the patient awakened clinically normal from the procedure despite my obvious concerns.

IV. Arteriotomy techniques

Some areas of controversy exist concerning technical performance of the carotid artery repair. It is difficult to find objective data on these subjects, no doubt owing to the difficulty in documenting the individual contribution of such minor factors to success or failure in large series of patients. A few topics, however, are worthy of mention.

Patch grafting: Most surgeons favor patch grafting of the ICA repair in cases of recurrent stenosis, and many employ patch grafts selectively in a prima-
ry repair where the ICA lumen has been sufficiently narrowed to raise questions about postoperative stenosis and possible thrombosis. As mentioned, I have gone to 100% patching with Hemashield graft material. The use of autologous vein incurs the risk of central patch rupture, with possible disastrous consequences. This risk is heightened in females, in diabetic patients, and with the use of saphenous vein material from the ankle or of the common facial vein. I no longer use vein patches for carotid artery repair. For those who choose to use a vein patch today a high femoral donor site, rather than the ankle, is recommended. Yamamoto's recent article citing the extensive Mayo Clinic patching experience is very instructive.

**Tacking sutures:** The use of tandem sutures to secure the distal intima in the ICA has been deemed unnecessary by some, yet has been cited by others as one of the major technical improvements in reducing carotid artery surgical morbidity. Although such sutures have the potential to narrow the ICA lumen, this risk is low in comparison to the possibility of intimal dissection if a loose flap is left behind, and the potential narrowing is inconsequential when a patch graft is used. Both Patterson and Ferguson, among others, point out that tacking sutures become unnecessary if the ICA arteriotomy is carried far enough to visualize normal intima distal to the plaque. These arguments are reasonable, and certainly I am a strong proponent of an arteriotomy that extends well above the zone of diseased ICA, however, I have not been entirely satisfied with the clean feathering of intima distally in some cases, and have become accustomed to placing distal tacking sutures in approximately 25% of my arterial repairs without ill effects.

**Heparinization:** Intravenous heparin is routinely administered at some point prior to arterial cross-clamping and repair. The dose, which may vary from 2500 to 10,000 units, appears to be of little consequence and is a matter of individual preference. I give 5000 units when the artery is first being dissected, and I do not reverse the anticoagulation. There is no evidence that this single dose of anticoagulant contributes to intraoperative or postoperative bleeding any more than the preoperative antiplatelet or anticoagulant agents most carotid artery patients have received. In my patients who are heparinized because of crescendo transient ischemic attacks (TIAs) or an intraluminal thrombus, I routinely operate with full anticoagulation on board, and I have occasionally maintained full heparinization postoperatively in patients with prosthetic heart valves or a contralateral symptomatic lesion requiring a second surgery. If meticulous attention is paid to technique this is not a problem.

Some surgeons recommend that the intraoperative activated clotting time be checked to insure adequate dosing. I have recently adopted this policy for patients who come to surgery on continuous heparin and who thus would not usually receive a bolus dose in the operating room. To my surprise many of these patients have been found to be inadequately anticoagulated and have required an extra dose.

**Surgical Technique**

There are several cardinal principles of carotid artery reconstruction: complete knowledge of the patient's vascular anatomy, complete vascular control at all times, anatomical knowledge to prevent harm to adjacent structures, and assurance of a widely patent repair free of technical errors.

It is my feeling that the meticulous anatomical dissection and identification of vital cervical structures needed to minimize postoperative complications can be achieved only with a bloodless field. Accordingly, I do not consider elapsed time to be a factor in the performance of carotid artery surgery. In my institution, carotid endarterectomy requires from 2 to 2.5 hours of operating time and the average cross-clamp time is between 30 and 40 minutes. No untoward effects from the length of the procedure have been observed in any patient and I am convinced that the risk of cervical nerve injury or postoperative complications related to hurried closure of the suture line are significantly reduced by meticulous attention to detail.

Two surgeons trained in the procedure are always present during carotid artery surgery. Both surgeons stand on the operative side, the primary surgeon facing cephalad and the assistant facing the patient's feet. The operative nurse may stand either behind or across the table from the primary surgeon. The patient is positioned supine on the operating room table with the head extended and turned away from the side of operation (Fig. 1). Several folded pillow cases are placed between the shoulder blades to facilitate extension of the neck and the degree of rotation of the head is determined by the relationship of the external carotid artery (ECA) and ICA on preoperative angiography. The carotid vessels are customarily superimposed in the anteroposterior plane, and moderate rotation of the head will swing the ICA laterally into a more surgically accessible position. In those patients where the ICA can be seen angiographically to be laterally placed, the head rotation need not be as great. On the other hand, occasional patients will demonstrate an ICA which is rotated medially under the ECA (I have termed this a
Fig. 1  I prefer a vertically oriented incision along the anterior border of the sternocleidomastoid muscle which tails off toward the mastoid process.

Fig. 2  What I call the “side-by-side” carotid configuration implies an internal carotid artery that is rotated medially to the external carotid artery on the anteroposterior arteriogram. This will significantly complicate exposure of the carotid system and needs to be determined preoperatively for best results. In the anteroposterior angiographic view (left), the internal carotid artery is visualized medial to the external carotid artery, while in the lateral view (right), they are superimposed.

A linear incision along the anterior portion of the sternocleidomastoid muscles is always used. This may go as low as the suprasternal notch and as high as the retroaural region depending on the level of the bifurcation. The skin and subcutaneous tissues are divided sharply to the level of the platysma which is always identified and divided sharply as well. Self-retaining retractors are then placed and the underlying fat is dissected sharply to the level of the platysma which is always identified and divided sharply as well. Retractors are left superficial at all times on the medial side to prevent retraction injury to the laryngeal nerves, but laterally may be more deeply placed. Dissection proceeds in the mid-portion of the wound down the sternocleidomastoid muscle until the jugular vein is identified. It is to be emphasized that the jugular vein is the key landmark in this exposure. In some corpulent individuals the vein is not readily apparent and a layer of fat between it and the sternocleidomastoid muscle must be entered to locate the

Fig. 3  The operative exposure (upper) shows the relationship of the three vessels. The common (C) and external (E) carotid arteries are readily identified. The internal carotid artery (I) is rotated medially and deep in the carotid sheath. With extensive mobilization of the internal carotid artery it assumes a more normal configuration (lower) and the operation can proceed safely.
jugular vein itself. If this is not done, it is possible to fall into an incorrect plane lateral and deep to the jugular vein. As soon as the jugular vein is identified, dissection is shifted to come along the medial jugular vein border and the vein is held back with blunt retractors. The importance of the blunt retractor in preventing vascular injury at this point cannot be overemphasized. In this process, several small veins and one large common facial vein are customarily crossing the field and need to be doubly ligated and divided (Fig. 5). The underlying carotid artery is soon identified once the jugular vein is retracted. Most often I come upon the common carotid artery (CCA) first and at the point of first visualization, the anesthesiologist is instructed to give 5000 units of intravenous heparin which as mentioned is never reversed. Dissection of the carotid complex is then straightforward, and the CCA, ECA, and ICA are isolated with the gentlest possible dissection and encircled with 00 silk ties (or vessel loops if preferred) passed with a right angle clamp. Rarely, in unusually high ICA exposures, a ligature carrier has proven useful to pass the tie about the distal ICA. Injection of the carotid sinus is not routinely used, however, the anesthesiologist is notified when the bifurcation is being dissected, and if any changes in vital signs ensue, the sinus is injected with 2–3 ml of 1% plain xylocaine through a short 25 gauge needle. Although the carotid complex is completely exposed the CCA and ECA are not dissected free from their underlying beds in order to prevent postoperative kinking and coiling of these vessels. These arteries are dissected circumferentially only in those areas where silk ties or clamps are placed around them. Posterior dissection is more extensive in the region of the ICA, where posterior tacking sutures may later be placed and tied. The superior laryngeal nerve lies beneath and behind the distal ICA, and can be injured by a carelessly placed cross-clamp; it should be identified and avoided (Fig. 6).

The CCA silk is passed through a wire loop which is then pulled through a rubber sleeve thereby...
facilitating constriction of the vessel around an intraluminal shunt if this becomes necessary. The ECA and ICA ties are merely secured with mosquito clamps. Particular attention is paid to the superior thyroid artery, which is dissected free and secured with a double loop 00 silk ligature. A hanging mosquito clamp keeps tension on this occlusive Pott’s tie. Occasionally multiple branches of this artery are identified on the preoperative angiogram and these must be individually dealt with so that no troublesome backbleeding will ensue during the procedure through ignorance of these vessels. It is also essential that the ECA silk tie (and subsequent cross-clamp), be placed proximal to any major external branches, lest unacceptable backbleeding occur during the arteriotomy and repair.

Proper placement of the retractors facilitates the control of the carotid system. The hanging mosquito ties and silk ties are draped over these retractor handles to keep the field uncluttered. Of particular note is a blunt hinged retractor which is invaluable in exposing the ICA when a far distal exposure is necessary (Fig. 7). Dissection of the ICA must be complete and clearly beyond the distal extent of the plaque before cross-clamping is performed. A clear plane can be developed if the jugular vein is followed distally and dissection follows the plane between the lateral carotid artery wall and the medial jugular vein border. By following this plane, the hypoglossal nerve is readily identified as it swings down medial to the jugular vein and crosses toward the midline over the ICA. I prefer to mobilize the nerve along its lateral wall adjacent to the jugular vein, after which it can be isolated with a vessel loop and gently retracted from the field. This has seldom yielded transient hypoglossal nerve paresis, which seems to result instead in cases where the nerve is not visualized and is blindly retracted. Inadvertent transection of the hypoglossal nerve has never been seen.

It is vital to have adequate exposure of the ICA and control distal to the plaque prior to opening the vessel. The extent of the plaque can be readily palpated with some experience by a moistened finger. There is also a visual cue where the vessel becomes pinker and more normal-appearing distal to the extent of the plaque. If high exposure is needed, several strategies are possible. The digastric muscle can be cut with impunity, although this is necessary only in a small percentage of cases. For extreme high exposure the mandible can be dislocated or surgically split, or the incision can be carried anterior to the ear as described by Pearson and Sundt. Nasotracheal instead of orotracheal intubation will allow the jaw to be held closed and will yield an extra 1 or 2 cm of exposure (this is unnecessary in edentulous patients, in whom the jaw closes readily and high exposure is simplified). Unfortunately many anesthetists are hesitant to perform nasotracheal intubation in patients who arrive at surgery heparinized, which limits the value of the technique in my practice.

When complete exposure is achieved, the final step in preparation for cross-clamping is to ensure that a small Javid clamp can be fitted in the region of the ICA and rotated 180° so that it lies underneath the vessel (Fig. 8). In most cases this requires additional adventitial dissection behind the vessel to create a “window” in which the clamp head can be freely turned. This important step is necessary to facilitate rapid insertion of an intraluminal shunt if required. I also use a sterile marking pen to draw the proposed arteriotomy line along the vessel, which is helpful in preventing a jagged or curving suture line.

The monitoring system is then rechecked and the encephalographer notified of impending cross-clamping. Once a suitable period of baseline EEG has been recorded, the CCA is occluded with a soft-shoe Fogarty vascular clamp and small, straight bulldog clamps are used to occlude the ICA and ECA. A #11 blade is then used to begin the arteriotomy in the CCA and when the lumen is identified, a Pott’s scissors is used to cut straight up along the marked line into the region of the bifurcation and then up into the ICA until normal ICA is entered (Fig. 9). The incision should be up the midline of the
vessel; lateral deviation will increase the difficulty of hemostatic arterial repair. In severely stenotic vessels with friable plaques the lumen is not always easily discerned and false planes within the lesion are often encountered; great care must be taken to ensure that the back wall of the carotid artery is not lacerated and that the true lumen is identified prior to attempted shunt insertion. A quick release of the ICA bulldog clamp can demonstrate the lumen by backflow if necessary.

Changes in the EEG mandate a rapid trial of induced hypertension. If there is no immediate reversal of these changes, an intraluminal shunt is used. Some surgeons prefer a "test occlusion" of the carotid tree, and remove the clamps to prepare for shunt insertion if monitoring changes are seen. I think this is unwise, for fear that the test clamping will loosen some potential embolic debris. My policy is to clamp the carotid artery and keep it closed until the repair is complete, protecting the ICA from embolization at all times.

I use a 15 cm straight shunt fashioned from a #8 pediatric feeding tube which is cut by the scrub nurse so that a black marker dot is directly in the center of the shunt. This type of shunt is now available in a commercial kit version including two shunt sizes and a special scissors to cut and remove the shunt (Loftus Shunt; Heyer-Schulte Neurocare, Pleasant Prairie, Wis., U.S.A.) (Fig. 10). The shunt is first inserted into the CCA and secured by pulling up on the silk ties; a mosquito clamp then holds the rubber sleeve in place to snug the silk around both the vessel and the intraluminal shunt. The shunt tubing is held closed at its mid-portion with a heavy vascular forceps, then briefly opened to confirm blood

**Fig. 8** A small Javid clamp is sized around the distal internal carotid artery (ICA) in case shunt placement is required. This clamp will snug the vessel around the shunt tubing, eliminating backbleeding. ECA: external carotid artery. From: Loftus CM: Carotid Endarterectomy: Principles and Techniques. St Louis, Quality Medical Publishing, 1995. Reprinted with permission.

**Fig. 9** The Pott’s angled scissors are used to cut directly up the center of the vessel wall, following the blue line previously drawn. ICA: internal carotid artery. From: Loftus CM: Carotid Endarterectomy: Principles and Techniques. St Louis, Quality Medical Publishing, 1995. Reprinted with permission.

**Fig. 10** The Loftus Shunt kit (Heyer-Schulte Neurocare, Pleasant Prairie, Wis., U.S.A.) is a commercial adaptation of the shunt I have always prepared by hand from a pediatric feeding tube. The advantages of this shunt are the atraumatic ends, tapered for easy insertion, the black marker band indicating proper shunt position, the small bulge to anchor the shunt in the common carotid artery, and the special scissors to facilitate shunt cutting and removal without compromising the suture material.
flow and evacuate any debris in the shunt tubing (Fig. 11). Suction is then used by the assistant to elucidate the lumen of the ICA and the distal end of the shunt tubing is placed therein. After the shunt is again bled flushing any debris from the ICA, the bulldog clamp is removed and the shunt is advanced up the ICA until the black dot lies in the center of the arteriotomy. The shunt, if properly placed, should slide easily up the ICA, and no undue force should be employed in order to prevent intimal damage and possible dissection. The small Javid clamp is then used to secure the shunt distally in the ICA. Visualization of the dot in the center of the arteriotomy confirms constant correct positioning of the shunt. A hand-held Doppler probe can be applied to the shunt tubing to audibly confirm flow.

With or without the shunt, the plaque is next dissected from the arterial wall with a Freer elevator. A vascular pick-up is used to hold the wall and the Freer elevator is moved from side to side developing a plane first in the lateral wall of the arteriotomy (Fig. 12). The plaque is usually readily separated in a primary case and I go approximately half way around the wall before proceeding to the other side. The plaque is then dissected on the medial side of the CCA and transected proximally with a Pott's or Church scissors. A clean feathering away of the plaque is almost never possible in the CCA and the goal here is to transect the plaque sharply leaving a smooth transition zone. Attention is then directed to the ICA where likewise the plaque is dissected first laterally and then medially and then an attempt is made to feather the plaque down smoothly from the ICA. However, I find in some cases no matter how far up the ICA I go that a shelf of normal intima remains and tacking sutures are required (Fig. 13). Attention is finally directed to the final point of plaque attachment at the orifice of the ECA. The vas-

Fig. 11  After placing the shunt down the common carotid artery (CCA) the tubing is flushed to eliminate air and debris. ECA: external carotid artery, ICA: internal carotid artery. From: Loftus CM: Carotid Endarterectomy: Principles and Techniques. St Louis, Quality Medical Publishing, 1995. Reprinted with permission.


Fig. 13  When tacking sutures are required they are placed from the inside out with a double-armed 6-0 prolene suture. The knot is thus left outside the vessel and the intimal edge is held down by the stitches. ICA: internal carotid artery. From: Loftus CM: Carotid Endarterectomy: Principles and Techniques. St Louis, Quality Medical Publishing, 1995. Reprinted with permission.
cular pick up is used to grip across the entire plaque at the ECA opening and, with some traction on the plaque, the ECA can be marsupialized such that the plaque can be dissected quite far up into that vessel. I like to free the external plaque by sweeping around it with a Penfield #4 dissector and/or a curved mosquito clamp so that it is well freed up before eversion/avulsion is attempted. The plaque usually stops at the first major external branch. Plaque is often tethered in the ECA by the bulldog clamp and as long as the plaque lumen is held closed with the heavy forceps, this clamp can be removed without untoward bleeding, allowing avulsion of the distal plaque. The bulldog clamp must be quickly reapplied to stem copious backbleeding that occurs when the plaque is removed from the ECA. It should be stressed that if plaque removal is inadequate in the ECA thrombosis may ensue which can occlude the entire carotid tree with disastrous results. If there is any question of incomplete removal of external plaque I do not hesitate to extend the arteriotomy up the ECA itself and close it via a separate suture line.

Following gross plaque removal, a careful search is made for remaining fragments adherent to the arterial wall. Suspect areas are gently stroked with a peanut sponge and every attempt is made to remove all loose fragments in a circumferential fashion, elevating them the complete width of the vessel until they break free at the arteriotomy edge. While it is important to remove all loose fragments no attempt is made to elevate firmly attached fragments which pose no danger of elevating or breaking off.

Several special aspects of plaque removal need to be considered. The simplest to remove are the soft, friable plaques with intraplaque hemorrhage and thrombus which dissect quite readily and from which fragments are easily removed. The more difficult are the severely stenotic, stony hard plaques in which a plane of dissection at the lateral border of the carotid artery may not be readily apparent. This situation is analogous to the gross appearance in a case of recurrent carotid artery stenosis. In several of my cases of this type, plaque removal even in the gentlest fashion resulted in areas of thinning where only an adventitial layer is left in the posterior wall of the carotid artery. These cases have been treated by primary plication with one or two double-armed interrupted stitches of 6-0 prolene placed in the same fashion as the tacking sutures and no untoward consequences have ensued. Likewise, I have occasionally encountered an intraluminal thrombus emanating from a congenital web or shelf in the lumen of the vessel and this has been successfully plicated with a posteriorly placed stitch of double-armed 6-0 prolene. In all cases, the goal is to leave as smooth an arteriotomy bed as is possible with minimal areas of denudation or roughness available as sites for thrombus formation. Finally I have recently encountered residual walls so thin that arterial bleeding resulted from the needle holes placed for tacking sutures (behind the vessel, distant from the arteriotomy site). If these do not stop with gentle pressure and/or surgical gauze I have occasionally fashioned an encircling patch of Hemashield graft material which is tied like a blanket around the vessel and sewn closed in top, tamponading the bleeding point. This is a rare and extreme solution, but an effective one.

Attention is then directed to the arterial repair. If desired the operating microscope can be brought into the field at this point, or in some cases a bit sooner to allow for removal of the small fragments under high magnification. My personal preference is to continue with 3.5× loupé magnification. As previously mentioned, tacking sutures are employed in the distal ICA in some of my cases. Double-armed sutures of 6-0 prolene are placed vertically from the inside of the vessel out such that they traverse the intimal edge and are tied outside the adventitial layer (Fig. 13). Most often two such sutures are used, placed at the 4 and 8 o’clock positions. I then proceed to fashion the Hemashield patch. The patch material is placed over the arteriotomy and cut to the exact length of the opening. After removal from the field, the ends are trimmed and tapered to a point with Church scissors. Each end of the patch is then anchored to the arteriotomy with double-armed 6-0 prolene sutures and the needles are left on and secured with rubber shod clamps (Fig. 14). The medial wall suture line is closed first, and a running non-

![Fig. 14 The Hemashield patch is secured at each end with an anchor stitch of 6-0 prolene and the needles are left attached for later use.](image-url)
The medial wall of the patch repair is closed first from the internal to the common carotid arteries and the two stitch ends are tied together (Fig. 15). When this wall is complete the suture line can be inspected from the “inside out” (Fig. 16). The crucial step in wall closure occurs at the corners, where exact visualization is needed to ensure that both walls are engaged evenly on the needle, that the bites are placed close together (1 mm apart or so), and that the suture is completely pulled taut by the assistant so that the walls will not spread apart when flow is re-established. In my experience the corner stitches are the ones most likely to leak with clamp removal, and placement of a reinforcing stitch later is especially difficult at the distal ICA corner sites, which may be obscured by the bulk of the distended vessel or by the “tunnel effect” of a high distal exposure. The lateral wall is then closed (with the remaining limb of the ICA anchor stitch) from the ICA to just below the level of the carotid bulb (Fig. 17). At this point the second arm of the CCA anchor stitch is used to run up the CCA lateral wall to meet the ICA limb. Small bites are taken just at the arterial edge throughout (being certain, however, that all layers are included) and sutures are placed relatively close together to prevent leaks. Care is also taken that no stray adventitial tags or suture ends are sown into the lumen where they might induce thrombosis. Several millimeters of unsewn vessel are left on the lateral wall ensuring room to remove the shunt, if one has been used (Fig. 18). After the electroencephalographer is again notified, the shunt
is double-clamped with two parallel straight mosquito-toes, then cut between them and removed in two sections, one from each end. A common error at this point is to mistakenly entangle the suture material in the shunt clamps and thereby hamper smooth shunt removal. With or without shunt, the arteriotomy is completely closed as follows: All three vessels are first opened and closed sequentially to ensure that backbleeding is present from the ICA, ECA, and CCA. The two stitches are then held taut by the surgeon while the assistant introduces a heparinized saline syringe with blunt needle into the arterial lumen. The vessel is filled with heparinized saline and in this process all air is evacuated from the intraluminal space (Fig. 19). As the stitches are drawn up and a surgeon's knot is thrown, the blunt needle is withdrawn allowing no air to enter. Seven or eight further knots are then placed in this most crucial stitch. The clamps are removed first from the ECA, then from the CCA and finally, some 10 seconds later, from the ICA (Fig. 20). In this fashion, all loose debris and remaining micro bubbles of air are flushed into the ECA circulation. Meticulous attention is paid to evacuation of all debris and air prior to opening the ICA in every case. However, in the rare case where there is a known ECA occlusion (although most of these can be reopened at surgery with an ECA endarterectomy) this technique is extremely crucial as there is no ECA safety valve and all intraluminal contents will be shunted directly into the intracranial circulation. When the clamps have been removed, the suture lines are inspected for leaks which are customarily controlled with pressure, patience, and surgicel gauze. In occasional cases, a single throw of 6-0 prolene is necessary to close a persistent arterial hemorrhage. Suture repairs of bleeding points are more likely if a patch graft has been placed. It is almost never necessary to reapply clamps to the artery if the repair has been properly performed (Fig. 21). The repair is then lined with surgicel and the three vessels are tested with a hand-held Doppler to ensure patency. Retractors are removed and hemostasis is confirmed both along the jugular vein and from the surrounding soft tissues. Persistent oozing is often

Fig. 19  A blunt needle is then inserted and heparinized saline fills the vessel while the knots are secured.


Fig. 21  The completed Hemashield patch repair should be widely patent and totally dry, with evenly spaced sutures and no kinking or rotation of the vessels.
encountered in these patients who have often received large doses of antiplatelet agents in addition to their intraoperative heparin. A final Doppler check is made and the wound is closed in layers. The carotid sheath is first closed to provide a barrier against infection, and the platysma is then closed as a separate layer to ensure a good cosmetic result. Either running or interrupted subcuticular stitches may be used to close the skin edges which are then apposed with steristrips. A hemovac drain is routinely used and left inside the carotid sheath. It is removed on the 1st postoperative day. Patients are restarted on aspirin the day following surgery and are discharged in 2–3 days.

I manage any postoperative neurological deficit, including TIA alone, with immediate angiography. In my experience lesser measures, such as duplex scanning, are inadequate to facilitate definitive surgical decision making in these patients where quick judgments and emergent surgery may be required. Any postoperatively occluded carotid artery is re-explored and repatched immediately, although since adopting the primary Hemashield patch repair my incidence of postoperative occlusion has been zero.

Special Surgical Considerations

Bilateral carotid endarterectomy: Bilateral carotid endarterectomy runs the risk of not only extreme swings of blood pressure from concurrent denervation of both carotid sinuses but also the risk of bilateral cranial nerve injury. For this reason, when bilateral carotid endarterectomy is required in my patients, I stage these procedures 6 weeks apart and have the patient examined by an otolaryngologist to ensure that no occult cranial nerve or vocal cord dysfunction is present prior to the second procedure. Unilateral nerve dysfunction in the cervical region is troublesome but a bilateral one can be disabling. I have, on several occasions, deferred second side surgery and maintained the patient on medical therapy when an occult vocal cord paralysis was diagnosed.

Intraluminal thrombus: The problem of surgical timing in patients with angiographically demonstrated propagating intraluminal thrombus remains an open question among cerebrovascular experts. In patients who present with TIA (which in my experience have always resolved with anticoagulation) and an intraluminal thrombus I have opted for delayed surgery (at 6 weeks, following repeat angiography) in every case, and have never seen a negative outcome from intercurrent embolization once heparin is instituted. Likewise there is a small subset of patients with postoperative neurological events (most often TIA) following carotid endarterectomy who are found to have a fresh thrombus adherent to the suture line, partially occluding the artery, and which is presumably the source of embolic phenomena. If there is no other angiographic evidence of technical inadequacy I have chosen to manage these patients conservatively as well, with full anticoagulation and 6-week follow-up arteriography. In every case the thrombus has resolved and there have been no negative neurological outcomes in our series with this plan of management. Despite the surgeon’s natural inclination to fix a problem with bold action, I have found that a measured conservative approach yields good results in cases of fresh or propagating thrombus and in our experience is superior to undertaking a high-risk surgical procedure.

Tandem lesions of the carotid siphon: In the North American Symptomatic Carotid Endarterectomy Trial (NASCET) symptomatic patients were excluded if the degree of siphon stenosis exceeded that at the carotid bifurcation. The presence of stenotic disease at the carotid siphon has been proposed as a contraindication to carotid endarterectomy because of both inability to pinpoint the symptomatic source and the reputed increased possibilities of postoperative occlusion from decreased carotid artery flow velocity. This has not been my experience, and I do not hesitate to operate on patients with tandem lesions if I am convinced that an active plaque at the carotid bifurcation is the source of their embolic phenomena.

Recurrent carotid artery stenosis: There is a small but finite incidence of recurrent carotid artery stenosis following primary carotid endarterectomy. Aside from technical inadequacies, it has been difficult to identify risk factors associated with recurrent carotid artery stenosis, although continuation of smoking habits following endarterectomy has proved to be a significant risk factor in several studies, whereas hypertension, diabetes mellitus, family history, lipid studies, aspirin use, and coronary artery disease may not be as important.

Reoperation for carotid artery stenosis is a technically difficult procedure. It is associated with significantly higher risks than primary endarterectomy. In our institution, the possibility of reoperation for carotid artery stenosis is entertained in patients who present with angiographically proven disease and classical neurological symptoms referable to the appropriate artery, or with documented progression to severe stenosis while being followed with annual serial duplex examinations.

Concurrent coronary/carotid artery disease: It is well established that patients with extracranial carotid artery disease have a higher than normal inci-
idence of coronary artery disease as well as other peripheral vascular problems. Indeed the risk of perioperative myocardial infarction exceeds the risk of perioperative stroke in many clinical series of carotid endarterectomy. Several major questions arise when planning treatment for concurrent coronary/carotid artery disease. These include first, what is the risk of coronary artery revascularization in a patient with a high-grade asymptomatic stenosis or bruit; second, in patients with symptomatic carotid artery disease, what is the appropriate work-up of the coronary circulation; and third, if surgical degrees of both carotid artery and coronary artery disease are identified in the same patient, what is the appropriate surgical management—staged carotid followed by coronary artery revascularization, combined procedure, or “reverse-staged” coronary artery revascularization followed by delayed carotid endarterectomy.

The first question regarding asymptomatic bruit in symptomatic coronary artery patients is straightforward. ACAS has now shown a surgical benefit for lesions ≥60%, and I recommend that these be staged prior to coronary artery revascularization whenever possible.

The second question regarding appropriate work-up of coronary artery disease in symptomatic carotid artery patients is a more difficult one. In this situation, work-up is customarily guided by the patient’s history and symptomatology. It has been my practice to obtain cardiology consultation in any patient with a history of angina, known heart disease, or abnormal resting electrocardiography. The work-up proceeds with a thallium stress test with exercise or dipyridamole, and if there is any evidence of myocardial ischemia coronary angiography is performed.

When the results of cardiac evaluation indicate the need for coronary artery revascularization, the question becomes one of timing of the surgical procedures. My preference is to do staged procedures whenever possible. With careful hemodynamic monitoring and good anesthetic technique, we are routinely able to perform safe unilateral carotid endarterectomies prior to coronary artery revascularization. An occasional patient with severe unstable angina may require a combined procedure but this entails a significantly higher surgical risk and I attempt staged procedures whenever possible. Most series dealing with “reverse-staged” coronary/carotid artery procedures (i.e. the coronary artery revascularization first with delayed carotid endarterectomy) discuss these in the context of asymptomatic carotid artery disease. Whereas I previously felt that “reverse-staged” procedures in asymptomatic patients were unindicated, I now feel that for unstable coronary artery disease with an unacceptable cardiac anesthetic risk a “reverse-staged” procedure may be appropriate since the ACAS data has validated surgery on silent carotid artery lesions.

In conclusion then, it is my preference to aggressively work-up any patient with cardiac symptoms prior to carotid endarterectomy. If procedures in both circulations are indicated, staged procedures are preferable unless the coronary circulation disease makes anesthesia for carotid endarterectomy an untenable proposition. In such case a combined procedure may be acceptable. I see no indication for “reverse-staged” procedures in symptomatic patients and would prefer to reconstruct asymptomatic carotid artery stenosis of ≥60% first whenever possible.

Conclusions

Now that cooperative study data is available to support the clear superiority of surgery in the management of both asymptomatic ≥60% and symptomatic carotid artery stenosis ≥70% carotid artery reconstruction will undergo continued technical refinements. There will be additional data forthcoming from NASCET for the “moderate” stenosis group of patients with linear stenosis of 30–69% when follow-up of this group is complete (this data is scheduled to be released in January 1998). The cerebrovascular surgical community will also face challenges from cardiologists and radiologists who seek to treat carotid artery patients with angioplasty and stenting. At present there is no level one evidence to support the efficacy of endovascular treatment, whereas such evidence clearly exists for surgical treatment.

Many of the basic neurovascular principles are standard, but we have seen relaxation of some old “taboos” (such as contralateral occlusion, tandem stenosis, and fresh stroke). In my opinion this expanded acceptance of carotid artery surgery arises from more rigorous training and credentialing of surgeons, improved monitoring and anesthetic techniques, and the scientific application of cooperative trial methodology to the carotid artery problem.

The surgical methods presented here have been successful in producing acceptable postoperative results in a broad spectrum of carotid artery patients. Minor technical details which may vary among surgeons are probably of little significance. On the other hand, subtleties of technique which may add operative time to the “routine” carotid artery surgery assume greater importance when difficult lesions or high exposures are encountered.

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or when the patient is unstable. The importance of a good outcome under these more difficult circumstances leads me to approach all carotid artery surgery, no matter how simple it may seem, with the same technical approach. Perhaps the most important factor in assuring technically acceptable carotid artery surgery is the availability of a skilled cerebrovascular surgeon with a demonstrable morbidity and mortality below 3% and a proper understanding of both vascular principles and cerebral physiology.

References

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