CAROTID ENDARTERECTOMY

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The first successful carotid artery resection was performed in 1951 by Carrea, Molins, and Murphy and, in 1953, DeBakey completed the first carotid endarterectomy (CEA). One year later, the potential benefit of surgical treatment for symptomatic carotid occlusive disease was highlighted by Eastcott and Pickering. Subsequently, in 1956, the use of a carotid shunt was described by Al-Naaman, Carton, and Cooley. In the 1990s, the first large-scale, multi-center randomized trials (North American Symptomatic Carotid Endarterectomy Trial and European Carotid Surgery Trial) demonstrated that CEA reduced the risk of stroke in patients with an ipsilateral symptomatic carotid stenosis. Currently, CEA is indicated to prevent stroke in patients with stenotic disease of the carotid bifurcation, specifically in asymptomatic patients with a carotid stenosis of more than 60% and features of high-risk for stroke and in symptomatic patients with a history of recent cortical neurological event (transient ischemic attack/stroke) or amaurosis fugax and ipsilateral carotid stenosis of more than 50%.

ANATOMY

The right common carotid artery (CCA) originates from the innominate artery behind the right sternoclavicular junction. The left CCA usually originates directly from the aortic arch. The left CCA can share a common ostium with the innominate artery (in 15% of the population) and it can also originate directly from the trunk of the innominate artery (in 8% of the population), both being referred to as bovine aortic arch configuration.

Each CCA ascends in the neck in the carotid sheath. The carotid sheath also contains the internal jugular vein lateral to the carotid artery, and the vagus nerve, which deeply lies between the carotid and the internal jugular vein. At the base of the neck, the CCA lies behind the strap muscles and the sternocleidomastoid muscle. However, as it ascends, the CCA becomes more superficial and is separated from the skin by respectively the platysma, partially by the sternocleidomastoid muscle, and the carotid sheath. At around the level of the fourth cervical vertebra, the CCA bifurcates into the external and internal carotid artery (ICA). Just below the bifurcation, the facial vein usually crosses the CCA entering the internal jugular vein.

The external carotid artery (ECA) lies anteromedial to the ICA. The first branch of the ECA is the superior thyroid artery, which may sometimes arise directly from the CCA. More cranial branches from the ECA include the ascending pharyngeal, the lingual, the facial, the occipital, the posterior auricular, superficial temporal, and internal maxillary arteries.

The ICA is divided into three main segments: the cervical, petrous, and intracranial segments. The cervical segment extends from the carotid bifurcation to the origin of the carotid canal at the base of the skull. It is crossed anteriorly by the hypoglossal nerve, the occipital artery, the digastric muscle, the stylohyoid muscle, and the posterior auricular artery. The ICA does not give off any branches in the neck. The petrous segment represents the ICA, as it advances in the carotid canal to lie in the petrous portion of the temporal bone and the intracranial segment represents the remaining part of the ICA, as it courses through the cavernous sinus before it pierces the dura to contribute to the cerebral circulation.

ANESTHESIA TECHNIQUE

Carotid endarterectomy can be performed under local, regional, or general anesthesia. Randomized trials have shown no evidence that a specific anesthetic technique is associated with reduced operative morbidity or mortality. Local anesthesia can be experienced quite stressful by both patient and surgeon and is, therefore, not recommended for patients with anxiety or those with difficult anatomy.

POSITIONING

The patient is positioned at the edge of the table of the affected side, with the neck in extension (Figure 17.1). The head is turned to the contralateral side and placed upon a soft rubber ring. Elevation of the shoulders with a rolled sheet between the scapulae enhances neck extension, particularly in patients with short, broad necks. The upper chest, lower face, and lower ear are prepped and draped.

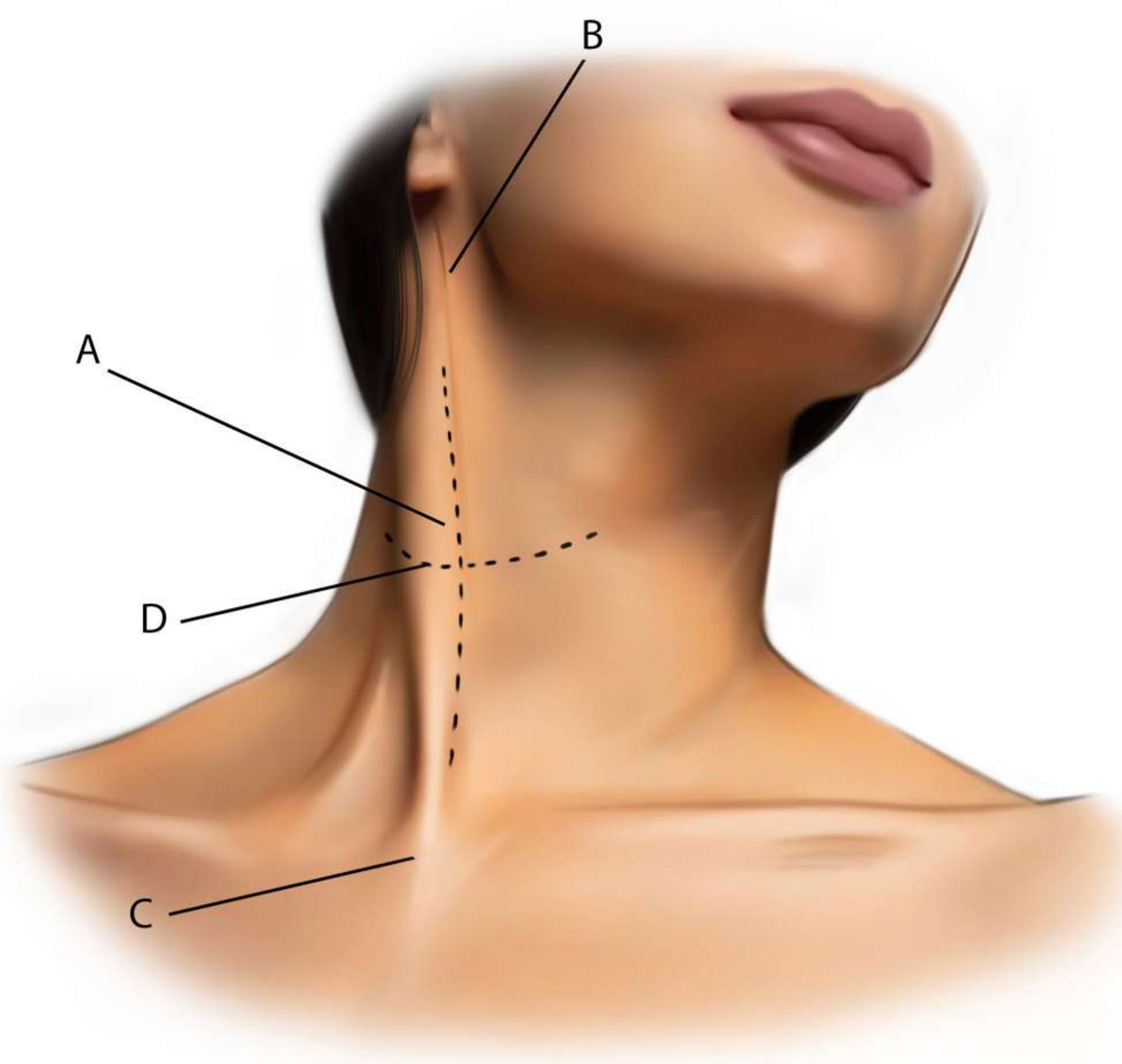


Figure 17.1. Positioning with neck in extension with head turned to the opposite side.

A: Length incision anterior to border of sternocleidomastoid muscle. B: Insertion of the sternocleidomastoid muscle; C: Origins of the sternocleidomastoid muscle; D: Transverse cervical incision.

Preoperatively, the level of the carotid bifurcation can be marked on the skin using ultrasound imaging (Figure 17.2).

EXPOSURE

Usually, a longitudinal incision along the anterior border of the sternocleidomastoid muscle is performed to expose the CCA and its bifurcation. A transverse neck incision along a flexion skin crease starting around 5 cm below the angle of the mandible can also be used (Figure 17.1). This incision requires the creation of skin flaps and can make things difficult, if a high exposure of the ICA is necessary. The longitudinal incision starts two fingers above the sternal notch and extends along the anterior border of the sternocleidomastoid muscle just inferior to the lobe of the ear and may need to be extended to the mastoid in distal, difficult lesions. The posterior displacement of the cranial incision helps to avoid injury to the marginal mandibular branch of the facial nerve. The incision is deepened, and subcutaneous tissues and the platysma muscle are incised using electrocautery, exposing the sternocleidomastoid muscle. The dissection is continued throughout the whole length of the incision along the medial border of the sternocleidomastoid dividing the small vessels that supply it. A self-retaining retractor is placed to retract the sternocleidomastoid muscle laterally, thereby exposing the anterior aspect of the internal jugular vein. Note that the spinal accessory nerve, which may cross from beneath the sternocleidomastoid muscle (cranial), is at risk of injury if the muscle is subjected to excessive traction.

Figure 17.2. The level of the carotid bifurcation has been preoperatively marked.

Dissection is now continued along the medial edge of the internal jugular vein. The attachments of the lateral aspects of the carotid sheath to the sternocleidomastoid are left undisturbed so that, when the sternocleidomastoid muscle is retracted laterally, the jugular vein will be retracted along with it. This manoeuvre requires division of the common facial vein, as well as division of other branches draining facial structures into the jugular vein. Once the internal jugular vein has been mobilized laterally, the carotid artery is easily identified.

A "minimal touch" technique is used for the dissection of an atherosclerotic carotid artery to prevent distal embolization. The technique for this is "dissecting the patient away from the artery, rather than extensive mobilization of the artery. At this stage, the vagus nerve should be identified and preserved. The vagus nerve is usually lying posteriorly between the carotid artery and the jugular vein. It is the nerve most injured during carotid endarterectomy. It can be damaged during dissection of the carotid artery or if inadvertently clamped while occluding the common or ICA. Once the CCA is freed from the surrounding tissue, it can be encircled with vessel loops away from the bifurcation area.

The ansa cervicalis is often noted crossing over the CCA and can be divided without any significant neurological damage, facilitating clearance of the tissues from the anterior surface of the carotid artery. The carotid dissection is, then, continued superiorly until the carotid bifurcation is reached. Dissection along the medial aspect of the CCA at the level of the carotid bifurcation will first identify the superior thyroid artery. Once it branches from the CCA, it should be isolated and controlled with double vessel loops. Further dissection superiorly exposes the ECA, which is looped as well. In case the patient develops bradycardia during carotid bifurcation dissection, lidocaine 1% should be infiltrated into the carotid body.

Dissection along the lateral border of the CCA leads to the ICA. Lymphatic tissue is often encountered between the carotid bifurcation and the digastric muscle. These lymphatic structures and small venous branches can obscure the location of the ICA and the hypoglossal nerve. It is of utmost importance to proceed very carefully at this level to avoid both bleeding and iatrogenic nerve injury. The hypoglossal nerve crosses the ICA at a variable distance from the bifurcation, usually parallel to the digastric muscle. It often runs medial and, thus, the ICA can be fully exposed without having to manipulate the nerve. However, mobilization of the hypoglossal nerve from lateral to medial is sometimes required. In particular, if the exposure is compromised by inadequate hemostasis, the hypoglossal nerve can be injured during the mobilization of the ICA. The ICA should be controlled 1 cm beyond the visible extent of atherosclerotic disease and encircled with loops (Figure 17.3).

In case of more distal ICA disease or the presence of a high bifurcation, it may be necessary to expose the ICA more cranially. This can be achieved by dividing the overlying muscles and mobilizing of the hypoglossal nerve. The ansa cervicalis is divided close to the hypoglossal nerve and used to provide gentle traction on the nerve. A branch of the occipital artery is often tethering the hypoglossal nerve and can be ligated and divided to allow extensive mobilization of the hypoglossal nerve. Division of the digastric muscle provides further exposure above the level of the hypoglossal nerve. Note that the mandibular branch of the facial nerve can be injured due to the direct compression by a handheld retractor applied below the angle of the mandible to improve the carotid exposure. Also, the posterior auricular nerve can be damaged, when the dissection is carried out along the anterior border of the cranial part of the sternocleidomastoid. Although very rare, mandibular subluxation in collaboration with the ear, nose and throat (ENT) surgeons is performed to facilitate exposure of the upper cervical segment of the ICA.

Endarterectomy

Before clamping, intravenous (IV) heparin (75-100 IU/kg) is administered. A proximal vascular clamp is applied to the CCA and a distal clamp, for instance, a Cooley clamp, to the ICA. Either the double vessel loop is tightened and pulled caudally around the ECA or the ECA is also clamped. It is vital to maintain adequate cerebral perfusion during clamping and the endarterectomy. Some surgeons prefer routine carotid shunting, whereas others the selective use of a shunt. When the operation is performed under local anesthesia, symptoms of cerebral hypoperfusion (after clamping) may show as the inability to follow verbal commands or as on-table seizure activity, indicating the need for

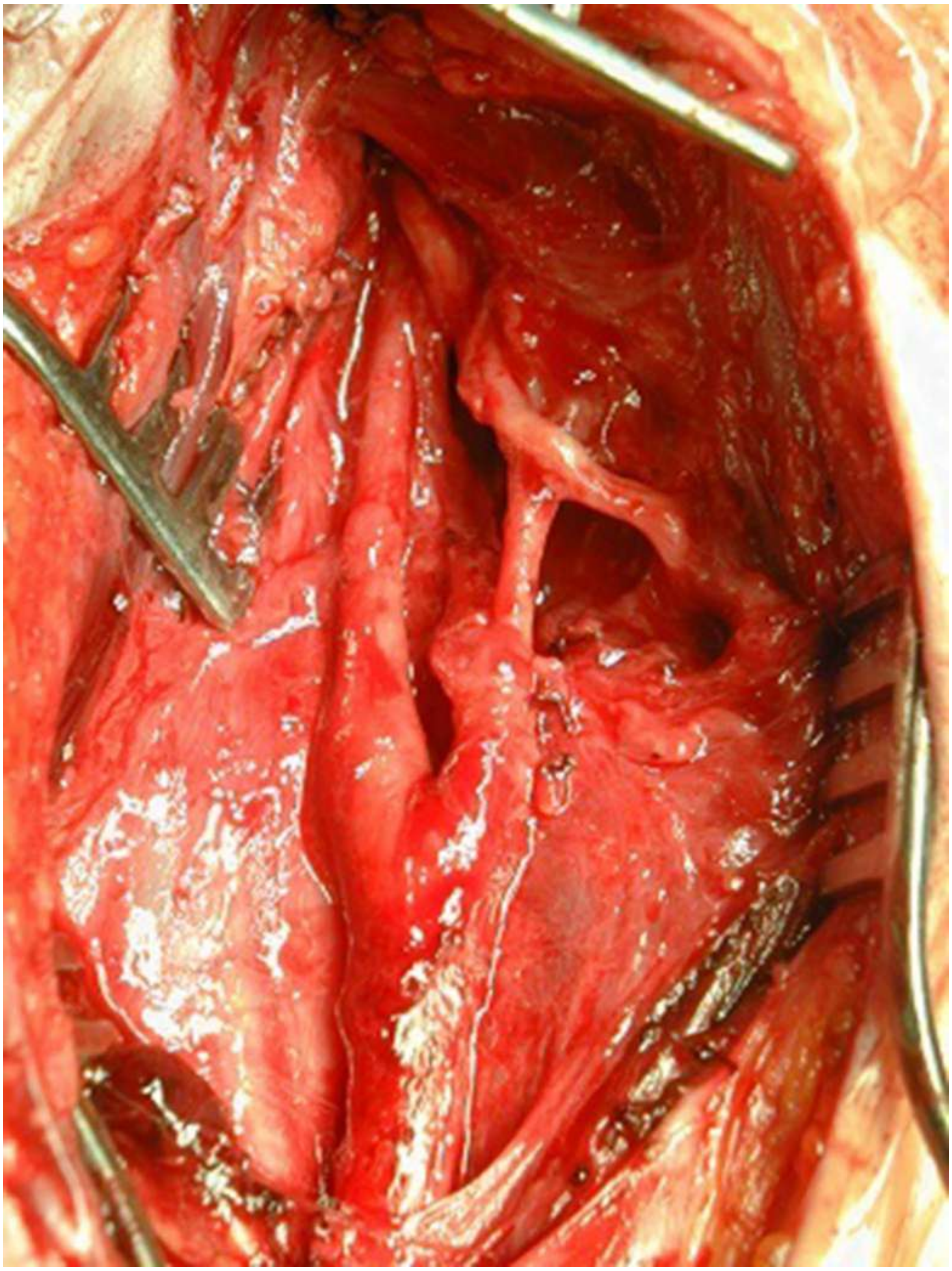


Figure 17.3. Exposure of the carotid bifurcation. Note the hypoglossal nerve crossing the internal carotid artery.

carotid shunting. Under general anesthesia, a change in cerebral monitoring (electroencephalogram, transcranial Doppler, cerebral oximetry) can be used as an indication for shunting. During cross-clamping, the systolic blood pressure should be maintained at or above the physiological level of the patient.

Carotid shunts

Several carotid shunts are available to maintain cerebral perfusion during carotid endarterectomy. The proximal end of the shunt is placed in the CCA and the distal end in the ICA. Shunts can be either inlying or outlying. The inlying shunt is straight and lies entirely in the lumen of the common and internal carotid arteries. The outlying shunt is longer than the inlying shunt. It is inserted with only the ends lying in the vessel lumen, while the remainder of the shunt extrudes as a loop outside the vessel. Performing endarterectomy is usually easier with an outlying shunt. However, the limbs of the shunts extruding from the lumen can make closure of the arteriotomy more demanding than with an inlying shunt. Surgeons should be familiar with the various shunts available and should use the one with which they feel most comfortable. After adequate insertion of the shunts and restoration of the flow, cerebral perfusion should be assessed by either Doppler flow probe on the distal ICA or transcranial Doppler flow measurements.

The shunts most commonly used include the Javid™, the Sundt™, and the Pruitt-Inahara™ shunts (Figure 17.4). The Javid™ shunt has two ends of different sizes with small bulges on either end of the shunt. These bulges serve to stabilize the shunt and prevent bleeding around it; this is achieved by applying special clamps on the common and internal carotid arteries at the level of the bulges. The Javid™ shunt is an outlying shunt. It is simple to use, but it is relatively rigid.

The Sundt™ shunt is made of silastic and is fairly soft. It has a metallic skeleton incorporated in its wall to help to maintain its tubular shape. This metallic skeleton prevents clamping the shunt. The Sundt™ shunt also has a bulbous portion on either end to help its stabilization, which is usually achieved with the use of vessel loops. The Sundt™ shunt is available in various sizes with an outlying or inlying configuration. Furthermore, the Pruitt-Inahara™ shunt has inflatable balloons at each end to stabilize the shunt with a side arm that allows flushing the lumen. As with the Sundt™ shunt, vessel loops are usually used to stabilize the proximal part of the shunt. The distal end may be stabilized with balloon inflation only. The shunt is provided with two syringes to inflate the balloons. A successful technique is to fill each syringe with just the amount of saline necessary to inflate the balloon to the desired size. This practice can help to avoid accidental overinflation of the balloons which may result in balloon rupture or intimal damage. In the

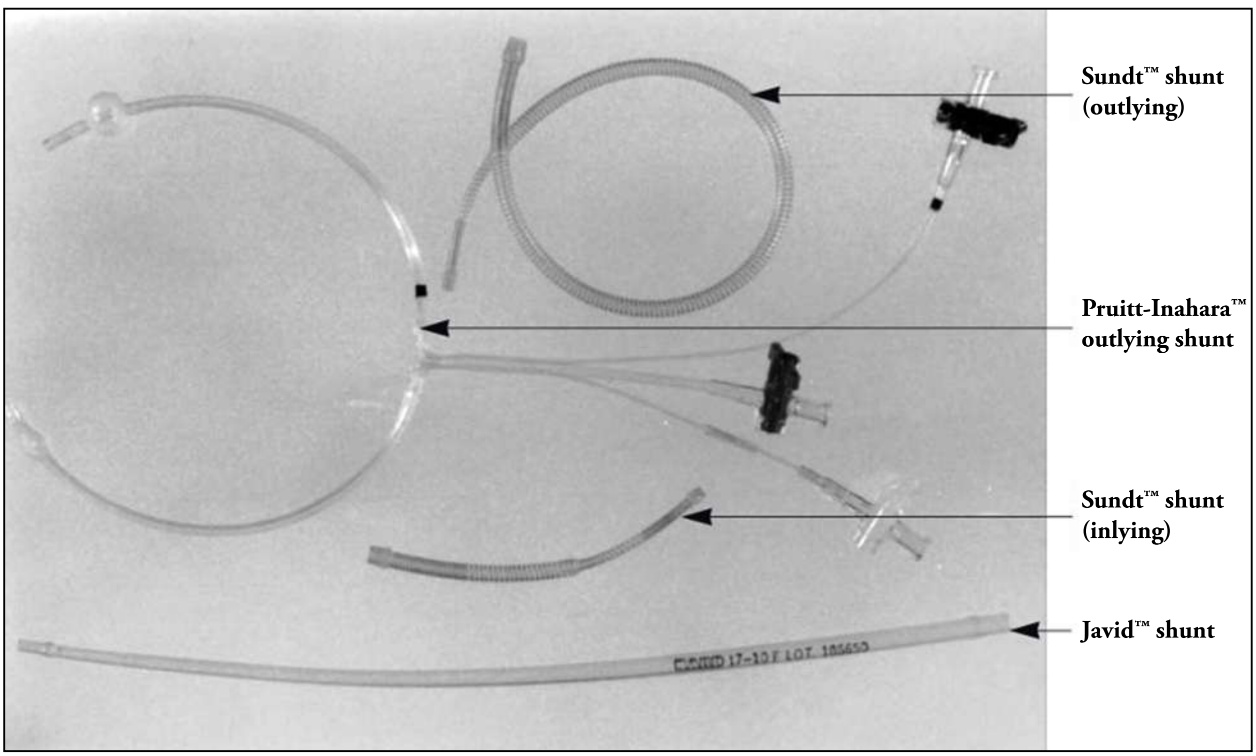


Figure 17.4. Most commonly used carotid shunts (Pruitt-Inahara™, Sundt™, and Javid™).

new shunts, the distal balloon is also attached to another small safety balloon placed along the distal arm of the shunt. The safety balloon will inflate, if the pressure in the distal balloon exceeds the acceptable limit.

Longitudinal endarterectomy

The arteriotomy incision is made in the distal CCA and ICA with angled Potts scissors. The atheromatous plaque is separated from the carotid artery by dissection in the layer between media and adventitia. Start by gently holding the edge of the adventitia with a forceps and pulling it away from the plaque. A plane will, then, develop. Using the Watson-Cheyne or Freer elevator, the adventitial wall is pushed away from the plaque. The endarterectomy plane is developed on each side of the vessel wall and advanced posteriorly, until it becomes circumferential. First the plaque extending into the ICA is removed, where it usually tapers distally, then plaque is removed from the ECA with the eversion technique and the carotid bifurcation

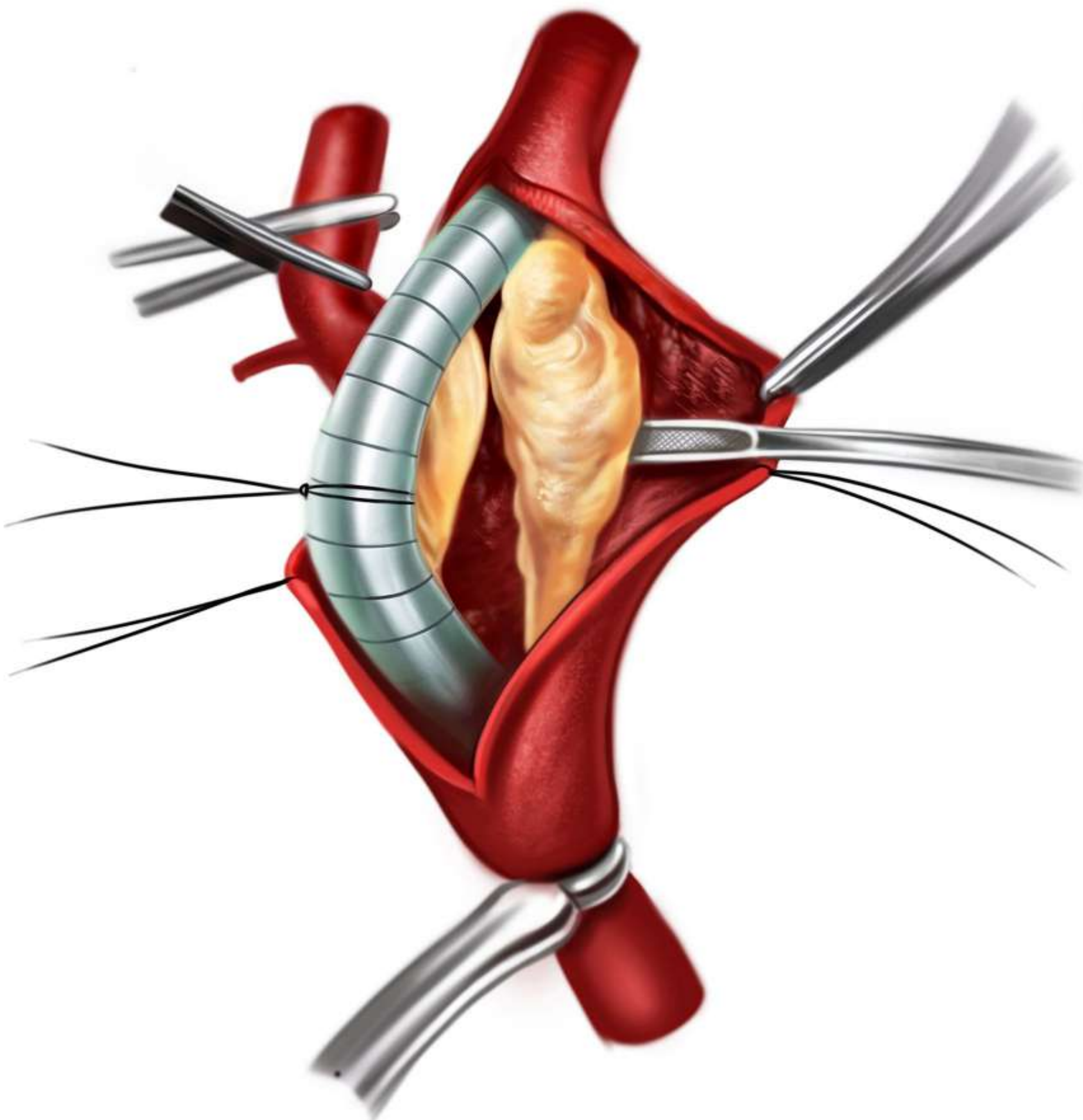


Figure 17.5. Longitudinal carotid endarterectomy using inlying shunt. The plane for the endarterectomy is developed with Freer retractor.

plaque is finally dissected proximally and sharply divided with Potts scissors (Figure 17.5). Irrigation at the endarterectomy site is performed with heparinized saline, removing loose fibers of the media or any flimsy tissue particles. If the distal end of the plaque is not firmly attached to the intima, two 7-0 polypropylene tacking (Kunlin) sutures are applied, entered from the luminal side and tied externally. Except in patients whose ICA has a very large diameter (>5 mm), closure of the arteriotomy with a patch (bovine pericardium, vein, Dacron, or polytetrafluoroethylene patch) is performed (Figure 17.6). Suturing is started distally in the ICA with a continuous 6-0 polypropylene suture using a parachute technique and continued proximally. The medial, proximal, and proximal half of the

Figure 17.6. Dacron® patch closure after right carotid endarterectomy.

lateral suture line is completed with one thread and, then, with the other thread the lateral side of the arteriotomy is continued from distally and almost fully completed leaving 5 to 10 mm open, depending on presence of a shunt. When a shunt is used, this is removed now. The backflow and forward flow are tested, and the artery is flushed with heparin saline. The remaining suture line closure is completed. After the suture line closure is completed, blood is first allowed to perfuse the ECA before the clamp on the ICA is removed. Adequate blood flow should be assessed after the patch completion by Doppler flow measurements in the CCA, ECA and distal ICA or by completion angiography.

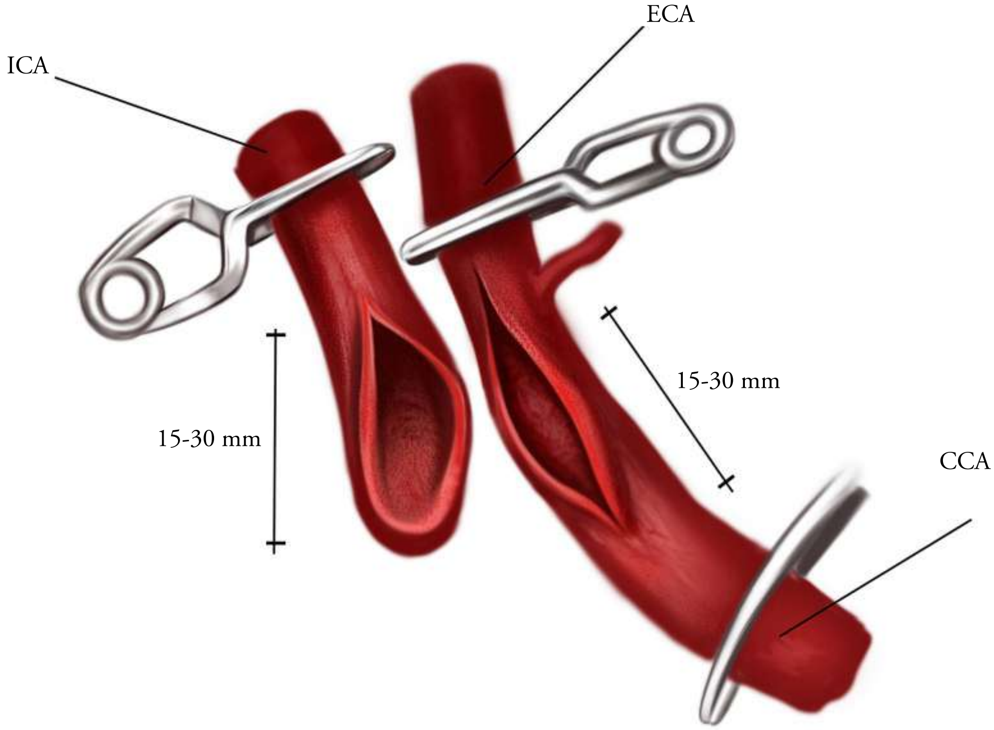
Eversion endarterectomy

The ICA is transected obliquely by dividing the carotid bulb from the carotid bifurcation on the lateral side of the CCA. In general, an opening of 10 to 15 mm can be obtained without extending the arteriotomy at either end, as long as the transection line is bevelled enough. Otherwise, the arteriotomy on the lateral wall of the CCA may be extended caudally and the arteriotomy medial wall of the ICA extended cephalad to a similar length to facilitate later anastomosis of the arteries. Eversion carotid endarterectomy is performed by circumferentially elevating the plaque with a Watson-Cheyne elevator from the arterial wall to remove both the intima and media; the adventitia is grasped with two fine forceps while an assistant holds the plaque. The adventitia with its outer layer of media is everted and the plaque is held away in tension, until the end is reached in the distal ICA (Figure 17.7). After removal of the plaque, the entire circumference of the end point should be inspected, loose fragments are removed with a fine forceps, and the distal intima should be adherent with no loose pieces. If a loose flap is found, it may be peeled off or alternatively “tacked” down using 7-0 double-armed polypropylene sutures from the luminal side and tied externally. After the end point is secured, the ICA is unrolled, and the luminal surface inspected for loose debris with irrigation of heparinized saline. Any loose fragments should be removed, and any persistent plaque or flap is identified and corrected before reanastomosis. Once the endarterectomy of the ICA is completed, the distal CCA and the ECA are inspected for plaque removal. The plaque is elevated in the bulb and carried up the ECA and proximally into the CCA. Endarterectomy of the ECA and CCA may be performed with direct elevation of the exposed plaque and proximal eversion of a more extensive plaque. The arteriotomy is irrigated with heparinized saline to remove loose fragments. To shorten an elongated or kinked ICA at the carotid bifurcation, the ICA is spatulated and pulled down onto the caudally extended arteriotomy in the CCA and the carotid kink is straightened. Primary anastomosis between the ICA and CCA is performed with continuous 6-0 polypropylene suture, starting at the most cephalad portion of the ICA arteriotomy. The back wall of the anastomosis is usually sewn from the inside of the artery, which provides the best visualization. The running suture is completed posteriorly and then brought anteriorly where it is tied to the other end (Figure 17.8). After completion of the anastomosis, blood flow is restored in the usual sequence: blood is first allowed to perfuse the ECA before the clamp on the ICA is removed. Adequate blood flow should be assessed after the patch completion by Doppler flow measurements in the CCA, ECA and distal ICA or by completion angiography.

Closure

Hemostasis should be assessed, including the patch anastomosis, jugular vein, ligated common facial vein and other venous branches into the jugular vein, and the sternocleidomastoid muscle. It can be effective to gently tamponade the patch with a gauze while starting hemostasis of the more superficial structures at the same time. A Valsalva maneuver can be performed to assess the integrity of the jugular vein. Protamine administration is recommended, particularly when patients are operated under double antiplatelet therapy with intraoperative heparin. It is optional to leave a Redon drain in the carotid sheath, which can be removed the next day. The sternocleidomastoid muscle is approximated with one or two 3-0 absorbable sutures. This will also hold the drain in place. Next, the platysma is closed with a 3-0 absorbable suture, and the skin is approximated with a 4-0 subcuticular suture. If the operation is performed under general anesthesia, the surgical nurse and instrument table should remain sterile, and the patient should remain in the operating room until the presence of any neurological finding that may warrant reexploration is excluded.

(a)



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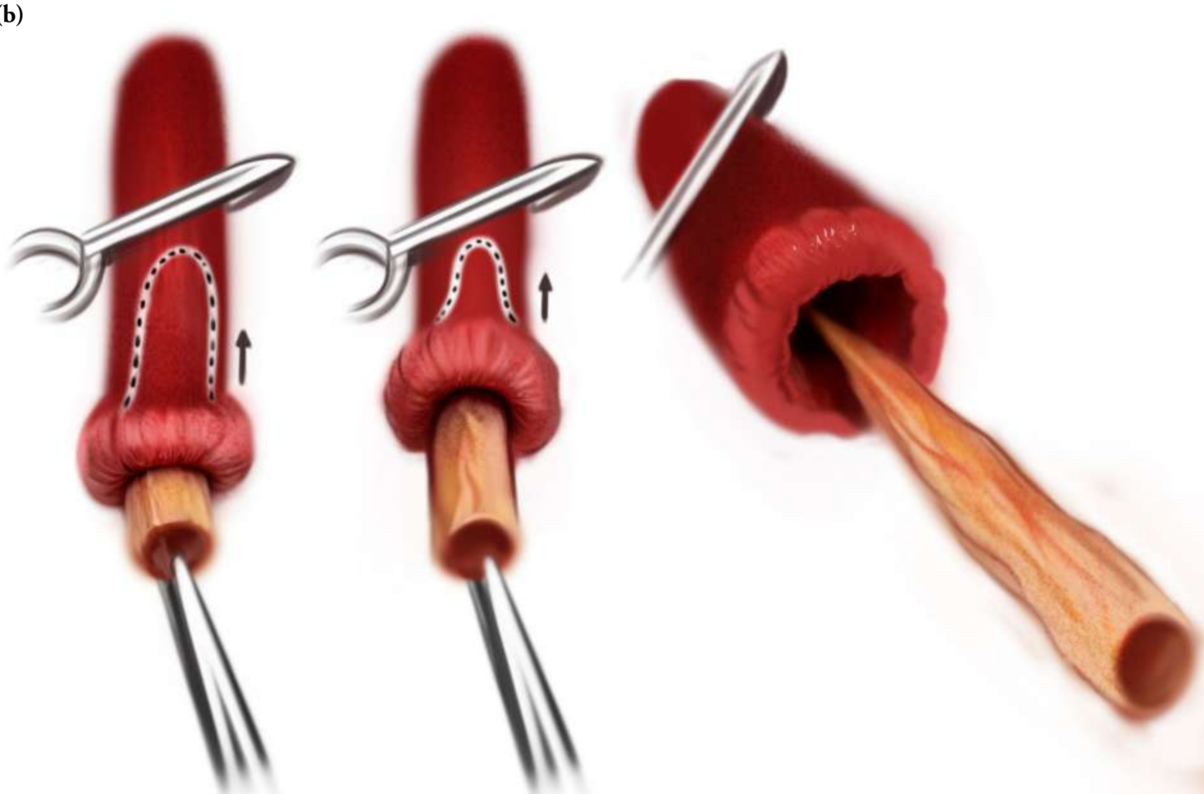

Figure 17.7. Eversion endarterectomy. **(a)** Arteriotomy by transecting the ICA from the bifurcation. **(b)** Eversion endarterectomy technique.

ICA: Internal carotid artery; ECA: External carotid artery; CCA: Common carotid artery.

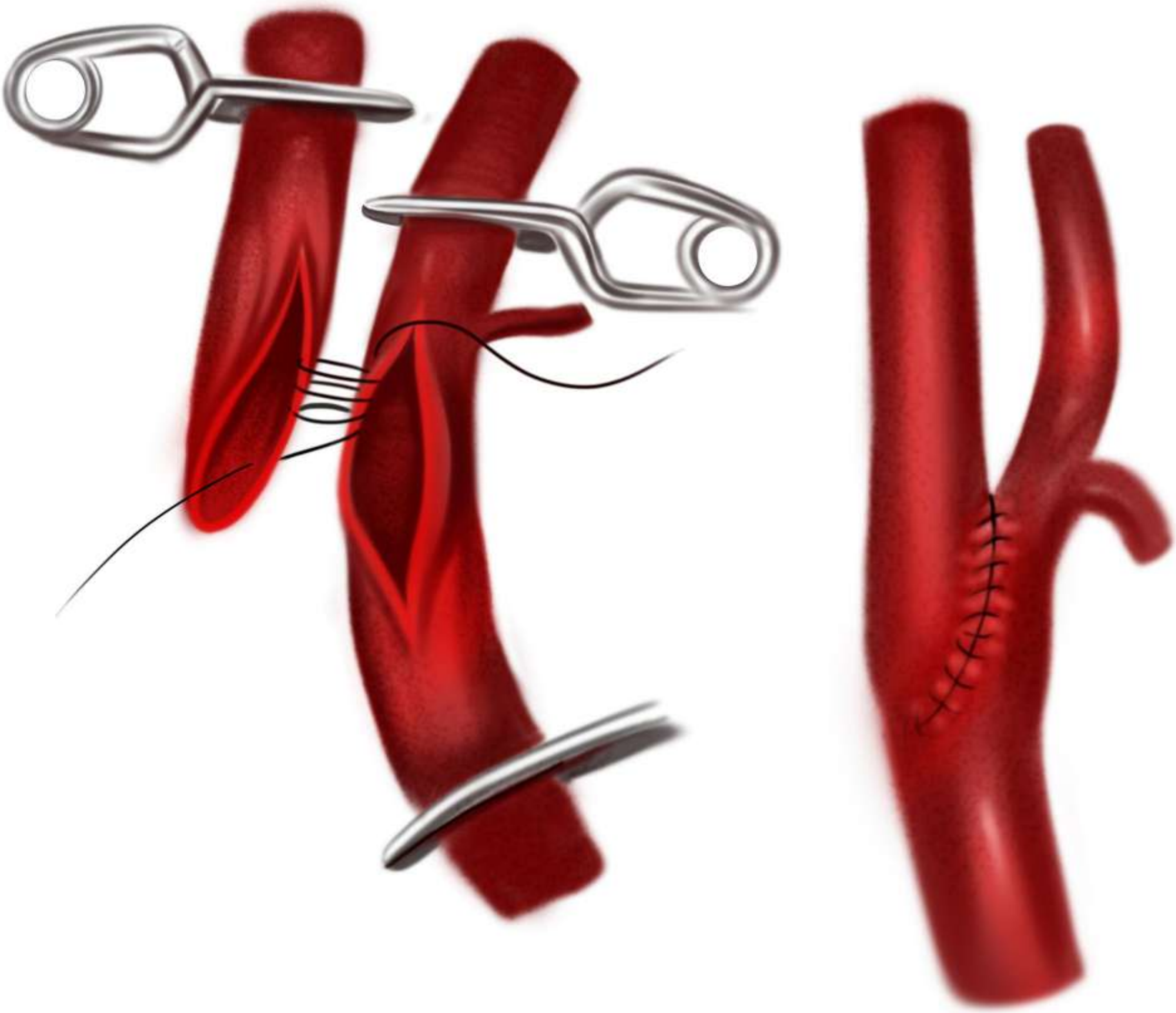

Figure 17.8. End-to-side anastomosis of internal carotid artery on carotid bifurcation, after eversion endarterectomy.

TIPS & PITFALLS

- The length of the incision can be shortened, if the carotid bifurcation is located preoperatively by Duplex scan. An experienced operator with an ultrasound machine in the operating room can do this in less than a minute.
- Regional cervical block is tolerated quite well and obviates the need for a shunt in over 90% of patients.
- If you plan to use a vein, do not forget to prepare a groin or ankle for vein harvest.
- The ideal position to access the neck fully is having the patient semi-sitting (30-45° Fowler) with the arms tucked in at the sides after insertion of arterial lines and proper intravenous access.
- Dividing the digastric muscle and ligating the small tethering vessel posterior to the hypoglossal nerve can help to expose the distal ICA.
- Be careful with dividing the facial vein; the hypoglossal can be adherent to it.
- Vigorous retraction can cause marginal mandibular nerve injury.

TROUBLESHOOTING

- There is no flow through the carotid shunt. Shunts may occasionally malfunction due to the position of the distal end of the shunt against the wall of ICA, for instance, at a coil or kink. Try to reposition the shunt a little more proximally or distally. If this does not result in adequate flow, the shunt may be occluded by thrombus or dissection. Take the distal end of the shunt out and assess adequate backflow and place the shunt again under vision.
- There is bleeding from the suture lines of the patch. First tamponade the bleeding, but if not sufficient use a 6-0 prolene to oversew leakages and do this always with the vascular clamps back on, to prevent tearing the thin endarterectomized wall.
- There is bleeding from the endarterectomized vessel wall. Use a piece of muscle or remaining patch to stitch tears in the vessel wall, while the vascular clamps are back on.
- There is no flow in the ECA. Lack of ECA flow implies a problem with the endpoint of the dissection and likely occlusion of the ECA, which in some patients may result in jaw or masseter muscle claudication. It is possible to reexplore the ECA; however, if the operation is difficult and a carotid shunt is required, this situation can better be accepted and left alone.
- There is no flow in the ICA. Reexploration is mandated when there is no ICA flow, even if the patient is free from any neurological deficits.
- There is ICA thrombosis. An emergent situation is thrombosis, and reexploration is mandatory. Acute thrombosis of the ICA is mostly caused by a technical issue at the end point, and this must be promptly evaluated and revised, as needed. A No. 2 or No. 3 Fogarty embolectomy catheter may be used to carefully retrieve a thrombus; however, the catheter length should be measured to avoid causing distal carotid damage or a carotid-cavernous sinus fistula. In most cases, retrograde flow from the ICA flushes the thrombus out and catheter extraction is not necessary.

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