Surgical Technique for Carotid Endarterectomy: Current Methods and Problems

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Abstract
Over the last 60 years, many reports have investigated carotid endarterectomy (CEA) and techniques have thus changed and improved. In this paper, we review the recent literature regarding operational maneuvers for CEA and discuss future problems for CEA. Longitudinal skin incision is common, but the transverse incision has been reported to offer minimal invasiveness and better cosmetic effects for CEA. Most surgeons currently use microscopy for dissection of the artery and plaque. Although no monitoring technique during CEA has been proven superior, multiple monitors offer better sensitivity for predicting postoperative neurological deficit. To date, data are lacking regarding whether routine shunt or selective shunt is better. Individual surgeons thus need to select the method with which they are more comfortable. Many surgical techniques have been reported to obtain distal control of the internal carotid artery in patients with high cervical carotid bifurcation or high plaque, and minimally invasive techniques should be considered. Multiple studies have shown that patch angioplasty reduces the risks of stroke and restenosis compared with primary closure, but few surgeons in Japan have been performing patch angioplasty. Most surgeons thus experience only a small volume of CEAs in Japan, so training programs and development of in vivo training models are important.

Keywords: carotid endarterectomy surgical technique, shunt, high plaque, monitoring

Introduction
Carotid endarterectomy (CEA) was first reported by Eascott et al. in 1954.1 Over the last 60 years, many reports about CEA have been published and techniques have changed and improved.2–4 Recently, despite the increasing use of carotid artery stenting (CAS), CEA remains an effective treatment for carotid artery stenosis both around the world and in Japan (Fig. 1).5,6 Particularly in patients with symptomatic carotid artery stenosis, CEA has been shown to be superior to CAS in several randomized studies and a meta-analysis.7–9

Some controversies remain regarding surgical strategies for CEA. In this paper, we review the recent literature about the operational maneuvers and techniques for CEA and discuss future problems.

Positioning for CEA
The most important point of discussion regarding positioning for CEA is how the operators extend the neck. All patients are placed in the supine position, then the head is placed on a firm holder and the neck is extended and turned away from the side of operation. Surgeons use various methods to extend the neck of the patient,4 and place a pillow under the neck and shoulder. One advantage of head rotation ≥45° is the possibility of dissecting the internal carotid artery (ICA) more distally or accessing a twisted carotid bifurcation.10,11 For expansion of the distal ICA, Takigawa et al. used a radiolucent head frame to extend the patient’s neck.12 In any case, the surgeon takes the head and neck position to expose the distal ICA for safe CEA (Fig. 2).

Skin Incision
The skin incision is decided based on two considerations: good exposure of the carotid artery and cosmetic effects. Traditionally, a longitudinal
incision has been made along the anterior margin of the sternocleidomastoid muscle (SCM) (Fig. 3A). The transverse incision, however, has been reported as a minimally invasive and cosmetic effect for CEA (Fig. 3B).\textsuperscript{11,13} Kazimierczak et al.\textsuperscript{14} reported a randomized study of camouflage (transverse) incision versus longitudinal incision. Although no significant difference in mortality or morbidity was seen between groups, scar assessment scale score was significantly better in patients with camouflage incision than in patients with longitudinal incision.\textsuperscript{14} However, if stenosis of the ICA extended to a high position, the transverse incision was limited to exposing the distal side of the ICA, and most surgeons use an extended longitudinal skin incision to improve distal ICA exposure (Fig. 3C). When we expose the upper edge of the platysma and SCM, attention must be paid to the great auricular nerve. This nerve exits from the lateral border of the SCM, crosses over the surface of the SCM and courses to the parotid gland and inferior part of the auricle. We should preserve this nerve as much as possible.\textsuperscript{15}

**Microsurgical Dissection of the Carotid Artery Using Mini-Hooks**

In the past, many surgeons have opened the surgical filed using various retractors. Mini-hooks with rubber
bands are used for lifting and developing the surgical field. The carotid artery is moved more superficially. Moreover, this system helps prevents nerve palsy and crush damage to surrounding tissues (Fig. 4).

Before the 1990s, most surgeons performed CEA without using a microscope. Since Spetzler et al. and Findlay reported on CEA using microsurgical techniques, most surgeons have adopted the use of a microscope for dissection of the artery and plaque. More recently, the high-definition exoscope has been reported as a novel instrumentation. While few reports have described the use of such devices in CEA, their use seems likely to increase.

Block of the Carotid Body

Post-CEA hemodynamic instability is associated with postoperative morbidity and mortality. Most surgeons perform local anesthetic blockade of the carotid sinus at dissection of the carotid artery to protect against hypotension during CEA. However, this effect remains controversial. Many studies have demonstrated that lidocaine blockade of the carotid sinus did not influence hypotension or bradycardia during CEA under general or local anesthesia. Tang et al. reported that no evidence currently supports routine use of local anesthetic to block the carotid sinus to reduce postoperative fluctuations in blood pressure. We may therefore use anesthetic blockade of the carotid sinus if we observe bradycardia or decreased blood pressure during dissection of or compression on the ICA.

Monitoring Technique in CEA

Several studies have discussed the best monitoring systems for use during CEA. Some of those studies considered the need for shunt, but some used monitoring to predict neurological deficit. To date, no monitoring technique during CEA has proven clearly superior to any other.

For many years, electroencephalograms (EEGs) and stump pressure have been used to monitor cerebral function and collateral cerebral flow during CEA. Stump pressure <40 mmHg has been used as the threshold for defining cerebral ischemia. Findlay et al. demonstrated CEA stump pressure <40 mmHg in 21% of 300 cases.

Recently, somatosensory-evoked potential (SSEP) has seen use as a standard method for monitoring CEA. Nwachuku et al. demonstrated that patients...
with perioperative neurological deficit were 14 times more likely to have shown changes in SSEP during CEA. Thiagarajan et al. reported that a change in either EEG or SSEP was 17 times more likely in patients with perioperative stroke, and dual modality monitoring was found to be more sensitive for predicting perioperative neurological deficit. Recently, transcranial Doppler (TCD), near-infrared spectroscopy (NIRS), and transcranial motor-evoked potential (MEP) have also been used for monitoring. Patients with perioperative stroke were four times more likely to have shown TCD changes during CEA compared to patients without stroke. Using TCD and NIRS during and after CEA, hyperperfusion can be predicted. Although cerebral ischemia of the middle cerebral artery area is detected by SSEP and/or MEP, that of the anterior cerebral artery (ACA) area remains undetected by these modalities. Therefore, a combination of SSEP, MEP, and NIRS to allow detection of cerebral ischemia in the ACA territory is very useful (Fig. 5).

We should choose the method of monitoring according to the purpose. Dual or multiple monitors offer better sensitivity for predicting postoperative neurological deficit.

Selective Shunt or Routine Shunt

Shunt usage during CEA has been the subject of considerable debate, with most surgeons favoring routine use or selective use based on the results of intraoperative monitoring. Cooley et al. reported shunt use during surgery on the carotid artery in 1956. Authors reported on external shunt as a new device and discussed the indications in 2001, 45 years after the initial report. We also demonstrated that in 30 of the 131 procedures (22.9%), intraoperative monitoring disclosed abnormalities after cross-clamping of the ICA using selective shunt during CEA. On the other hands, several arguments have been made against the use of routine shunts, including unnecessary use in approximately 80–85% of patients. Aburahma et al. reported a prospective randomized study comparing routine and selective shunting. They showed that both groups were associated with low stroke rates (routine shunt vs. selective shunt: 0% vs. 2%, p = 0.498), with no significant differences in outcome. At present, the individual surgeon should select the method with which they are comfortable.

Dissecting the Distal ICA Plaque

Distal ICA exposure is necessary to obtain distal control in patients with high cervical carotid bifurcation or high plaque. However, the definition of high cervical bifurcation is still ambiguous. Hans et al. divided the ICA into three zones and defined a high plaque as located above Zone 2. Hans et al. also mentioned chin-up and extension of the neck intubation and a chin-up position can be helpful to expose the distal ICA (Fig. 2B). Weiss et al. described this method as obtaining as much as 2.5 cm of more distal exposure. Takigawa et al. also mentioned chin-up and extension of the neck intubation and a chin-up position can be helpful to expose the distal ICA (Fig. 2B). Weiss et al. described this method as obtaining as much as 2.5 cm of more distal exposure.
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as useful.\textsuperscript{12} However, CAS is currently selected in most of patients with high plaque, so nasotracheal intubation is rarely adopted. Moreover, we should consider the side effects such as nasal bleeding and infection in the respiratory tract.

Temporary mandibular subluxation\textsuperscript{49,56,57} or mandibular osteotomy\textsuperscript{58} have been used for exposure of high distal ICA sites. These techniques are useful to expose more distal sites of the ICA, but are more invasive for the patient, and use of these methods has decreased.

On the other hand, as a minimally invasive method, several surgeons cut the ansa cervicalis at the origin to lift the hypoglossal nerve.\textsuperscript{51,53,59} If the occipital artery gets in the way of securing the distal site of the ICA, it can be cut (Fig. 7).\textsuperscript{51,53,59} A high plaque can be managed in almost all cases using these methods.

**Protection Against Embolic Complications and Lower Cranial Nerve Palsy**

The major cause of ischemic complications associated with CEA is embolism.\textsuperscript{60,61} To protect against embolic complication, several reports have examined different methods during exposure and dissection of the carotid artery. First, we administer heparin intravenously to reduce thrombus formation during ICA clamping. Hannan et al. reported that all surgical specialists used heparin extensively, with 97.5% of all patients having received heparin.\textsuperscript{62} Other strategies to avoid or minimize intraoperative cerebral plaque embolism have been reported. Pratesi et al. and Bourke et al. reported early control of the distal ICA during CEA.\textsuperscript{38,63} They demonstrated that use of this modified surgical strategy was independently associated with a lower risk of developing intraoperative neurological deficit.\textsuperscript{38,63} Yoshida et al. showed another method, named the “flow-control” CEA technique.\textsuperscript{61} They clamped the proximal common carotid artery (CCA), external carotid artery and superior thyroid artery, then dissected the bifurcation of the CCA and ICA before clamping the distal ICA. Under this method, new embolic lesions as detected by diffusion-weighted MRI were significantly decreased compared with the conventional method of CEA.\textsuperscript{61}

Lower cranial nerve injuries during CEA represent a considerable complication.\textsuperscript{64} The reported frequency

![Fig. 6 Definition of high plaque. (A) Definition of high plaque by Hans et al. The ICA is divided into three zones, with high plaque defined as that located above Zone 2. (B) Various definition of high plaque. Yellow line is the mastoid-mandibular line. Red line is the intersection of the occipital artery and internal carotid artery. White line is the C1 transverse process-hyoid bone line. ICA: internal carotid artery.](Image)
of cranial nerve injuries in patients who underwent CEA ranges from 2% to over 50%. Most of these nerve injuries are transient, and vagus nerve and/or hypoglossal nerve palsies are the most common. Most of these injuries are due to excessive retraction, and we therefore have to pay attention to protecting against lower nerve injuries. Several strategies have been reported. During carotid artery dissection, trauma may occur if the dissection is not kept close to the wall of the artery. The vagus and/or hypoglossal nerves are sometimes retracted excessively, and we therefore have to perform sharp dissection of the nerve and vessels, and remove excessive tension on nerves by detaching them from the surrounding tissues. Aldoori et al. reported that the pharyngeal veins, which drain into the internal jugular vein, should be cut if they cross over the hypoglossal or vagus nerve.

**Patch Angioplasty vs. Primary Suture**

The ideal surgical technique for vessel closure during CEA remains controversial. In Japan, primary closure of the carotid artery is common. However, multiple studies have shown that patch angioplasty after CEA reduces the risk of stroke and restenosis compared with primary closure. Some studies have shown a high risk of restenosis after 5 years in patients with primary closure. A recent meta-analysis by Rerkasem et al. demonstrated that carotid patch angioplasty reduced the combined perioperative and long-term risks of stroke and restenosis. In contrast, some retrospective studies have shown no significant difference between primary closure and patch angioplasty for postoperative outcomes and restenosis.

Considerable debate remains over the choice of patch material. Biological, synthetic (e.g., Dacron or polytetrafluoroethylene), or vein patches have traditionally been used in CEA. Hemostasis time is longer in CEA with PTFE patch than in that with venous patch or Dacron patch. The overall perioperative and long-term mortality rates, stroke rates, frequency of restenosis, and operative time appear similar between these patch materials. Saphenous vein patch angioplasty has been shown to be prone to aneurysmal dilatation and suture rupture with a rate of 0.1–4%, and many surgeons have thus changed to using synthetic patch recently.

**Skin Closure**

Before skin closure, some surgeons administer protamine to reverse the heparin. No consensus has
yet been reached about reversing the effects of heparin at the end of CEA. However, several reports have demonstrated that use of protamine is associated with a reduction in bleeding complications, without increasing major thrombotic outcomes, including stroke, myocardial infarction, or death.\textsuperscript{62,79,80} Another point is whether to use a subcutaneous drain insert at the skin closure. Smolock et al.\textsuperscript{51} demonstrated that drain placement shows no benefit. However, many surgeons in Japan still place a subcutaneous drain.

**Effect of Surgeon Experience on Perioperative Outcomes**

Several studies have demonstrated better outcome of CEA at high-volume centers. AbuRuhma et al.\textsuperscript{82} reported that high-volume surgeons (≥30 CEA/year) achieved significantly better outcomes than low-volume surgeons (stroke/death: 1.3% vs. 4.2%, \( p = 0.005 \)). Another point is the difference in outcome of CEA between experienced and younger surgeons. Several reports have demonstrated similar complication rates compared with experienced and younger surgeons.\textsuperscript{83,84} Gacioppa et al. reported a teaching program for trainees learning CEA. With this program (5 years of training), trainees can obtain results similar to those of experienced surgeons in terms of outcomes of CEA.\textsuperscript{85}

In Japan, most surgeons encounter only a small volume of CEAs, and gaining experience with a sufficient number of cases is difficult. We have already reported on training models as an “in vivo” CEA procedure,\textsuperscript{86} but the extent to which such models have gained acceptance is hard to say.

**Conclusion**

CEA had been performed as a relatively constant maneuver, but new maneuvers and equipment have been introduced over the course of 60 years. The technical aspects of CEA have changed little by little, but room for discussion remains in various aspects. To maintain the CEA procedure, improvements and the establishment of safer techniques are necessary.

**Conflicts of Interest Disclosure**

The authors have no conflicts of interest to declare regarding this study or its findings.

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