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CEREBROVASCULAR

Use of Intraoperative Duplex Ultrasonography for Identification and Patch Repair of Kinking Stenosis After Carotid Endarterectomy: A Single-Surgeon Retrospective Experience

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Key words
- Carotid endarterectomy
- Intraoperative duplex ultrasonography
- Kinking
- Restenosis

Abbreviations and Acronyms
CEA: Carotid endarterectomy
EEG: Electroencephalography
ICA: Internal carotid artery
IDUS: Intraoperative duplex ultrasonography
MCA: Middle cerebral artery
PSV: Peak systolic velocity


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OBJECTIVE: **To provide an incidence and descriptive evaluation of kinking of the internal carotid artery (ICA) after carotid endarterectomy (CEA) in a consecutive CEA series that included the use of intraoperative duplex ultrasonography (IDUS) monitoring and to determine the effect of kink patch repair on long-term postoperative ICA restenosis.**

METHODS: **The electronic medical records and IDUS recordings of all CEA cases performed over a 10-year period (March 2000 to October 2010) by a single neurosurgeon were retrospectively reviewed to assess cases of kinking after CEA.**

RESULTS: **IDUS assisted in the identification of 27 of 285 cases (9.5%) of kinking after CEA. Kinked vessels with hemodynamically significant peak systolic velocities of ≥120 cm/second on IDUS (11 of 285 cases; 3.9%) were repaired using a synthetic patch. During follow-up, there were no neurologic symptoms, stroke, or death related to a cerebrovascular accident associated with kinking. The total incidence of postoperative stroke in this CEA series was 3 of 285 cases (1.1%).**

CONCLUSIONS: **ICA kinking stenosis after CEA was a common finding in this CEA series. Because of their unique anatomic and hemodynamic properties, the identification and assessment of kinks after CEA required the use of IDUS monitoring. A selective patch closure method for kinked vessels with peak systolic velocities of ≥120 cm/second identified by IDUS was effective in resolving hemodynamically significant stenosis and minimizing long-term postoperative restenosis.**

INTRODUCTION

The use of intraoperative duplex ultrasonography (IDUS) in carotid endarterectomy (CEA) has allowed for a more careful evaluation of technical aspects of the

Table 1. Categories for Internal Carotid Artery Diameter Stenosis Based on Duplex Ultrasound Measurement Values

ICA Diameter Stenosis (%)	ICA/CCA PDV Ratio (I)	PDV (cm/second) (II)	ICA/CCA PSV Ratio (III)	PSV (cm/second) (IV)
0–40	<2.6	<40	<1.5	25–110
41–59	<2.6	<40	<1.8	>120
60–79	>2.6	>40	>1.8	>130
80–99	>5.5	>80–135	>3.7	25–250

Numerals I–IV represent order of criteria importance (I, most important; IV, least important) in determining the category for ICA diameter stenosis.
ICA, internal carotid artery; CCA, common carotid artery; PDV, peak diastolic velocity; PSV, peak systolic velocity.

repair, assisting in the identification of residual intraluminal defects that may arise from the arterial reconstruction. Published studies have linked unrepaired residual hemodynamic abnormalities detected by IDUS to an increased risk of ipsilateral perioperative stroke or other neurologic deficit (15, 28), restenosis (7, 26), and late ipsilateral stroke (18). By providing surgeons the opportunity to identify and correct technical errors in the carotid repair at the time of surgery, the use of IDUS may afford better clinical outcomes for patients undergoing CEA.

In our experience with CEA, we have encountered many cases of internal carotid artery (ICA) kinking after CEA detected during intraoperative assessment using duplex ultrasonography. Kinking of the ICA is a sharp angulation of the vessel that may be a significant source of stenosis (19, 34). It is seen at the distal end of the repair and appears to result from hydrodynamic forces after primary (direct) closure of the arteriotomy and removal of the cross-clamp. The phenomenon is not associated with the presence of residual atherosclerotic plaque, vessel elongation, or other predisposing factors for ICA kinking previously cited in the literature. Rather, it appears to be related to an interaction between the reduced thickness of the arterial wall after endarterectomy and hydrodynamic forces after flow restoration. The defect is apparent only after completion of the primary closure and removal of the cross-clamp, when the carotid artery can be interrogated under the force of systolic arterial pressure.

Although ICA kinking stenosis occurring after CEA has been included in the list of common CEA technical defects by many investigators, studies providing an incidence of kinking after CEA in a consecutive CEA series have been limited. No reports have yet described kinking stenosis occurring after CEA based on anatomic and hemodynamic characteristics; offered parameters for correction based on IDUS assessment; or followed the postoperative natural history of both repaired and unrepaired kinks to assess their role, if any, in postoperative cerebrovascular events or restenosis. This retrospective report describes a single neurosurgeon's 10-year CEA experience using IDUS for the identification of ICA kinking stenosis after CEA and selective (discretionary) patching for the intraoperative repair of this defect.

METHODS

Patients

Between October 2000 and March 2010, a single neurosurgeon (Q.J.D.) performed 285 CEA operations on 225 patients using IDUS interrogation. To identify cases in which ICA kinks were detected intraoperatively by IDUS, the operative and ultrasound reports from the day of surgery for all CEAs were retrospectively reviewed using an electronic medical records system. Archived, videotaped recordings of IDUS monitoring assisted in the assessment of cases of ICA kinking occurring after CEA based on kink ultrasound appearance and flow characteristics. Data pertaining to patient demographics, medical history, indications for surgery, and postoperative evaluations were also obtained through electronic medical records.

Postoperative clinical and ultrasound evaluations were performed at 6 weeks, 4–8 months, and 9–24 months after surgery. Clinical evaluations included assessment of current neurologic status, with documentation of postoperative cerebrovascular or neurologic symptoms. For postoperative ultrasound evaluations, duplex ultrasonography assisted in obtaining ICA and common carotid artery peak systolic velocity (PSV) and peak diastolic velocity, from which ICA and common carotid artery PSV and peak diastolic velocity ratios were calculated. Categories related to the degree of ICA stenosis were determined from these velocities and ratios, along with other criteria derived from Spencer (32) and criteria used at the Center for Neuroscience, Orthopedics, and Spine certified vascular laboratory (Table 1). Under these guidelines, the occurrence of clinically significant postoperative vessel restenosis was defined as having a ≥60%–79% diameter stenosis.

Surgical Technique

All procedures were performed with the patient under general endotracheal anesthesia. A standard, open vascular technique is used for all CEA cases that includes IDUS monitoring, electroencephalography (EEG), and transcranial Doppler. Before clamp placement, the patient was given a dose of heparin (100 units/kg IV) and etomidate or propofol (or both) to induce EEG burst suppression for cerebral protection. When EEG changes related to the cross-clamp or to unstable ipsilateral middle cerebral artery flows were observed, a shunt was placed to prevent a sustained reduction in ipsilateral EEG amplitude or middle cerebral artery transcranial Doppler flow (to a velocity <20 cm/second). Selective carotid patching is used based solely on IDUS assessment of the carotid artery after completion of the endarterectomy and primary closure. The patch used is an IMPRA polytetrafluoroethylene patch (Bard Peripheral Vascular, Tempe, Arizona, USA) that is sutured in place over the stenotic kink after reopening of the primary closure in cases where patching was necessary to create a hemodynamically satisfactory lumen. After final closure, protamine sulfate (0.5 mg intravenously [IV] per 100 units of heparin) was administered to reverse the effect of heparin.

Intraoperative Assessment

For IDUS monitoring, an ATL HDI 3000 ultrasound machine (Philips Healthcare, Andover, Massachusetts, USA) was used